Design research on systems thinking approach in veterinary education

Li-Shan Tao
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Design research on systems thinking approach in veterinary education

by

Li-Shan Tao

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY

Co-Majors: Education (Curriculum and Instructional Technology);
Human Computer Interaction

Program of Study Committee:
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Iowa State University
Ames, Iowa

2015

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DEDICATION

To

my parents,

Zih-Wen & A Pin,

and my husband,

Nicolai,

For all the support, love, and caring.
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ABSTRACT

The purpose of this study was to investigate the application of a newly designed systems approach to the problem of students’ lack of big-picture experience in the College of Veterinary Medicine. To determine whether students’ performance on problem-solving for various scenarios improved after intervention\(^1\), a design research methodology was adopted to develop a systems-approach teaching and learning environment. Three iterations were conducted, with improvements to the instructional approach following each of the first two iterations.

The results supported the hypothesis that instructional intervention led to modest but statistically significant increases in students’ use of system thinking across the three experimental studies. However, the instructor indicated the need for faculty systems-approach training, whereas students tended to request hands-on practice to understand and retain systems thinking skills.

Furthermore, there was a significant improvement from pretest to posttest for the beef scenario, demonstrating transfer of systems thinking to a topic for which systems-approach instruction was not provided.

The qualitative data suggested that most students found systems thinking was beneficial for macro systems, such as food production, but not for micro systems such as individual small-animal biological systems.

\(^1\) The intervention was instructional innovations that applied systems thinking on problem solving to the subject matter.
CHAPTER I. INTRODUCTION

This chapter provides an overview of general systems theory and the systems approach including their definitions and current work in medical and related fields. Following a review of current needs in Veterinary Medicine (Vet Med) education and how general systems theory and the systems approach can help address these needs, an overview of the design research methods and how these methods are appropriate for the current study are described. Finally, the purpose and research questions addressed by the study are presented.

General Systems Theory

In 1928, Ludwig von Bertalanffy, a leading biologist with scientific and cultural interests, first discussed the idea of general system theory in his book entitled Modern Theories of Development (von Bertalanffy, 1928/1962). Then, in 1937, he presented the concept of general system theory in a philosophy lecture at the University of Chicago (Gray & Rizzo, 1969) and in that same time period coined the term “general system theory” (von Bertalanffy, 1972). He later published “General System Theory” (von Bertalanffy, 1972). Von Bertalanffy (1928/1962) believed that the customary investigation of single parts and processes cannot provide a complete explanation of the vital phenomena or give us information about the coordination of parts and processes. Thus, the chief task of biology must be to discover the laws of biological systems at all levels of an organization (p. 64).

General systems theory has been defined as a logico-mathematical discipline, under circumstances such as Newton’s law, which is applicable to all sciences concerned with systems, for example, biology and medicine (von Bertalanffy, 1950). It is a doctrine of principles that applies to all systems as a general theory of organization (von Bertalanffy, 1950). Von Bertalanffy (1950) noted that the existence of general system properties is
associated with the appearance of structural similarities or isomorphies in different fields. This means that concepts of organization, wholeness, directiveness, teleology, control, self-regulation, and differentiation in physics are also found in the biological, behavioral, and social sciences (von Bertalanffy, 1956). The most important effect of general systems theory is that it brings scientific work from all areas into a relevant and transacting relationship with the modern world (Gray & Rizzo, 1969).

The term “general systems theory” was later adopted by von Bertalanffy (1972) for the following reasons. First, some people might limit the term “general system theory” to its “technical” meaning, but there were many “system” problems asking for “theory.” Second, the term general systems theory is similar to the “theory of evolution,” which comprises many elements ranging from fossil digging to underlying mathematical theories. Third, the term general systems theory is similar to “behavior theory,” which extends from bird watching to sophisticated neurophysiological theories. It is the introduction of a new paradigm that matters. To be consistent with these ideas, the term “general systems theory” will be used throughout this dissertation.

As an example, the parts of a physical system may include a spring, a mass, and a solid ceiling, unrelated to each other without an obvious connection other than, for instance, being in the same room. Relationships of physical connectedness are introduced when the spring is hung from the ceiling and the mass is attached to the spring. In addition, new relationships among certain attributes of the parts may be introduced. The length of the spring, the distance of the mass from the ceiling, the spring tension, and the size of the mass can all be related. The system is static when these attributes do not change with time, but the mass may have a certain velocity depending on its size and the spring tension. Therefore, the
system becomes dynamic when the mass’s position changes with time. This example exemplifies Aristotle’s statement, “The whole is greater than the sum of its parts.”

According to general systems theory, this example of a physical system also applies to another familiar example: a high-fidelity sound system. In this example, the individual parts, including the turntable and arm of the record player, the amplifier, the speaker, the cabinet, and the electrical coupling between input and output would not behave as a sound-producing system without connections. With connections, these parts and their attributes become related. The performance of each component is dependent on the performance of the others; for instance, “mechanical vibrations in the speaker are related to currents and voltages in the amplifier” (Hall & Fagen, 1956). In other examples taken from the realm of biological phenomena, whether embryonic development, metabolism, growth, activity of the nervous system, or biocenoses, the behavior of an element is different within the system than in isolation. Instead of describing the behavior of the whole as a sum of its isolated component parts, the relations among the various subordinate systems and the systems that are superordinate to them must be taken into account to understand the behavior of the parts (von Bertalanffy, 1950).

In another example, the exponential law or law of compound interest can be applied to situations other than currency. With a negative exponent, this law applies to numerous phenomena, including the decay of radium, the monomolecular reaction, the killing of bacteria by light or disinfectants, the loss of body substance in a starving animal, and the decrease of a population in which the death rate is higher than the birth rate. With a positive exponent, this law applies to the individual growth of certain microorganisms; the unlimited Malthusian growth of bacterial, animal, or human populations; the growth curve of human
knowledge as measured by the number of pages devoted to scientific discoveries in a textbook on the history of science; and the number of publications on Drosophila. The entities concerned—atoms, molecules, bacteria, animals, human beings, or books—are very different in nature, and so are the causal mechanisms involved. Nevertheless, the same mathematical law governs their behavior (von Bertalanffy, 1950).

In summary, there are two main concepts in general systems theory. First, analysis of a system in one field, such as physics, may be applicable to other systems in disparate fields such as sociology or biology. Second, a whole is not equal to the sum of its parts; the relationships among various subordinate systems and the quality of parts within each system must be taken into account as a whole. Systems are dynamic when their parts or the relationships among their parts change over time. The systems approach in education has been established based on these two concepts, and this approach is introduced in the next section.

**Systems Approach**

First, the definition of a system for the purposes of this study should be provided. A system has been defined as (a) any group of purposefully interrelated things, materials, or abstract (Neil, 1969); (b) a collection of things connected together (Anderton, 1969); and (c) a complex of interacting elements that stand in certain relation (von Bertalanffy, 1950). The elements behave differently with respect to different relationships when there is an interaction. In contrast, the elements behave independently when there is no interaction. For example, in statistical regression there is an interaction when the independent variables behave differently when in relation R1 rather than in a different relation R2. On the other
hand, there is no interaction when there is no difference in the way the independent variables behave in relation to R1 and R2.

Based on general systems theory, Finn (1967) described the systems approach in the field of education as the creation of systems of instructional materials covering an area of subject matter in a systematic way designed to achieve rather precise objectives. For example, books, manuals, recordings, films, programmed materials, and tests are creations of systems of instructional materials covering subject matter in the areas of mathematics, language, history, geography, biology, physics, chemistry, etc. Neil (1969) defined the systems approach as a method that enables one to effectively and efficiently teach complicated objectives involving people, time, money, and other resources. For example, in an educational setting, a systems approach uses an exploratory method to find effective ways of talking about, designing, and organizing learning situations in practice, relating teachers and their students to the whole structure of an educational system (Neil, 1969). Neil indicated that a systems approach helps people view and conceive of a project in practice as a whole, considering it as more than just the sum of its parts.

For example, the systems approach can be used to analyze a scenario of neonatal diarrhea in piglets. In this scenario, a veterinarian has been called in as a new consultant for a farrow-to-wean sow operation. The farm is in the process of replacing their females (herd rollover) with a new genetic line. The new genetic line of females has been arriving at the farm for the past 8 months. The farm manager wants to improve his grow–finish performance and overall herd health and is currently concerned about the high number of scouring piglets produced in farrowing. The performance problem in this scenario might be described as
the percentage of pigs with loose stools is above a target (action) goal of x% and with
death rates at acceptable levels. Sampling output of the system (e.g., ill pigs) reveals
infection due to two different agents. Historical inputs into the system such as feed,
water, and new pigs are reviewed. (Personal communication, Alejandro Ramirez,
January 25, 2012)

Students are expected to be able to analyze the system— in this case, the nursery barn. This
analysis might reveal that the presence of an infectious agent is not the only reason for the
deviation in performance. Unlike the systems approach, the traditional approach requires
students to assimilate content, acquire knowledge, or memorize information and then
regurgitate it on a content-based exam. No analysis occurs, and other reasons that may have
caused the problems are not revealed.

**Systems Thinking**

Systems thinking is the practice of concentrating on how a group of connected things
act and interact with one another (Anderton, 1969). Richmond (1990) described systems
thinking as a problem-solving technique built upon a multidisciplinary and holistic view
instead of considering each single problem individually. In systems thinking, problems or
changes that create issues are parts of a structure within a system, and they reflect situations
(Richmond, 1992). When a problem comprises a phenomenon different from that of a
previous occurrence or when a given machine behaves differently from another, decision
makers must determine whether the differences are threats or opportunities, the source of the
differences, and what the differences are likely to bring about. Changes are not always
negative; they can be threats or opportunities depending on how one looks at them.
Sometimes a threat turns out to be an opportunity. People should practice systems thinking
and determine whether individual differences or changes from one situation to another are a
problem. Systems thinking is an important part of an effective strategy for addressing challenges and closing the gap between challenge and capacity. It evolves people’s thinking, communicating, and learning capacities when addressing issues that challenge their viability (Richmond, 1994).

People draw conclusions and make decisions by constructing a mental model and running multiple simulations of the mental model, creating feedback (Richmond, 1992). In order to diagnose and design solutions to complex problems, Richmond (1992) employed eight systems-thinking skills for mental construction and simulation, communication, learning, and action. These skills are 10,000-meter thinking, system-as-cause thinking, dynamic thinking, operational thinking, closed-loop thinking, nonlinear thinking, scientific thinking, and empathic thinking (Table 1.1). Such systems-thinking skills are the main techniques used in the systems approach for teaching and learning. Some of the concepts of systems thinking, including 10,000 meter, dynamic, feedback, and scientific thinking, have been adopted from the general systems theory.

By using systems-thinking techniques, people are able to raise systems questions when solving a problem by integrating their knowledge into a bigger picture that considers multiple components, systems, and environments. For example, students in a high school science class in Arizona learned how the physics component of thermodynamics affects many aspects of the world in which they live, including for example, plate tectonics, cumulonimbus cloud build-up, and anatomical and physiological adaptation of animals to control heat gain and loss (Draper, 2010). The instructor who taught this class believed that the world is made up of dynamic and interconnected systems and that students should always be thinking of feedback and circular causality. These concepts should be taught from the
Table 1.1

*Eight Systems-Thinking Techniques*

<table>
<thead>
<tr>
<th>Technique</th>
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<tr>
<td>1  10,000-meter thinking (forest thinking)</td>
<td>This thinking helps people build the big picture, e.g., to see a forest at 10,000 meters from an airplane in the sky. It is a structural dimension.</td>
</tr>
<tr>
<td>2  System-as-cause thinking</td>
<td>This thinking considers whether a system itself, such as a slinky, is the cause rather than external forces, e.g., gravity or the release of one side of the slinky from one hand</td>
</tr>
<tr>
<td>3  Dynamic thinking (filtering thinking)</td>
<td>This thinking helps people build a pattern of historical events and economic points that provide a non-static view of reality. It is a behavioral dimension.</td>
</tr>
<tr>
<td>4  Operational thinking</td>
<td>This thinking helps people consider when and how to include delays (reality) in stocks (realized impacts, things that accumulate) and flows (things that flow).</td>
</tr>
<tr>
<td>5  Closed-loop thinking</td>
<td>This thinking helps people conduct more reliable simulations by viewing the reality of closed feedback loops.</td>
</tr>
<tr>
<td>6  Nonlinear thinking (reinforcing feedback loop)</td>
<td>This thinking provides a mental vehicle (delivery) to capture delay (reality), anticipate an action’s impact, and address concerns upon graduation.</td>
</tr>
<tr>
<td>7  Scientific thinking</td>
<td>This thinking helps people simulate good principle practices.</td>
</tr>
<tr>
<td>8  Empathic thinking</td>
<td>This thinking helps people easily cross-disciplinary boundaries by listening to others and clearly articulating a mental model.</td>
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beginning of a class. During class sessions, students learned scientific and dynamic thinking via class lessons and by observing cumulonimbus storm cloud build-up. First, the instructor introduced the idea of a causal loop by the feedback relationships between rising warm air, ambient cooler air, vapor-to-liquid phase changes, latent heat release, and the continuing rising of air. Second, students saw with their own eyes the towering cumulonimbus clouds in an afternoon at the Santa Catalina Mountains and the feedback relationships among water condensation, cooling, and lifting.

In another exercise, students learned closed-loop and generic thinking through observation of homeostasis and a poikilotherm’s behavioral and physiological responses to various external temperature conditions. In a model of animal temperature, students
compared the sizes of animals, their insulation, ambient air temperature, and whether animals were warm- or cold-blooded. Students learned not only the role of ambient temperature in determining heat loss rates but also animal size-dependent adaptations. By the end of the animal temperature model-building exercise, students had improved their thinking by entering information they gathered into the Stella modeling and simulation software. In the exercise, the instructor did not specify which problem answers were “right” or “wrong” but provided a mental model that could be explicitly related to a big picture. While confronting what they thought they knew with new information, students reconsidered how the world works in a new paradigm.

The instructor suggested that, for deep and continuing learning, teachers and students must enter into a mentor/apprentice relationship wherein all of the thinking skills must be demonstrated through real problem-solving by the teacher interacting with the students, not just covering a regular lesson. A similar situation occurs in higher education, such as in the setting of the current study, the College of Veterinary Medicine (Vet Med) at Iowa State University (ISU). Students in that setting should learn systems-thinking skills through real problem-solving scenarios working interactively with faculty, instead of just covering the basic materials in regular lessons (Hurd, 2009).

**Current Needs in Veterinary Medicine Education**

Today’s food systems require a high level of veterinary expertise, including the ability to address economic, biosecurity, biological-waste, animal-welfare, food-safety, and public-health concerns (Bernardo, 2006). There is a serious shortage of veterinarians to support the supply chain for safe and healthy food (Hurd, 2009). To support this supply chain, veterinarians must understand the implications of their decisions throughout the food,
environment, and public health systems. They must understand the systems approach to problem solving, which represents a new need in the area of veterinary medicine. However, Veterinary Medicine instructors typically use scientific reductionism in teaching, i.e., an animal is a sum of its parts (Hurd, 2009). According to Hurd, each production system is taught individually. Current Veterinary Medicine students are overloaded with information, and there is not sufficient time for more courses, labs, or rotations. As a result, Hurd argued that a majority of Veterinary Medicine students lack a big-picture view of the global food-safety environment. This is the problem investigated by this study.

Grounded in general systems theory, the systems approach was adopted in this dissertation study to reconstruct Veterinary Medicine students’ strategies for problem solving and decision making. The systems approach presents problem scenarios promoting diagnostic analysis based on a big picture and trains students to ask systems questions. In effective systems-approach education, instructors work closely with systems trainers to develop new frameworks, curricula, and delivery mechanisms for transforming the mindset and skill set of, in this case, Veterinary Medicine students tasked with safely feeding the world. With a systems approach, Veterinary Medicine students’ problem-solving abilities can be improved. A systems approach can help the students develop a broader understanding of the entire food production system and be effective in new situations. This ability is important, because with time it will support development of new treatments and vaccines. Possessing an understanding of a system and how its component parts interact may allow a student to easily adopt new tools and techniques into his or her practice. From the earlier example of neonatal diarrhea in piglets, holistic concepts such as herd immunity, pig flow, micro- and macro-environmental impacts, etc., may possibly be applied in managing more
complex problems. This implies not just a change in thinking but also a change in concepts and principles taught.

In this study, design research methodology was adopted to create a systems-approach teaching and learning environment for the first time in the College of Veterinary Medicine. This study was intended to determine whether students exhibit greater levels of systems thinking following intervention than prior to intervention and to obtain information from students and instructors to improve intervention quality. The iterations were variations of the design based upon assessments collected from preceding operation of the system. In the present educational case, the system was the modified curriculum that was implemented, the assessments were pre- and posttests as well as interviews, and the goal was to graduate students who could apply systems thinking to their profession.

Based on general systems theory, the systems approach helped instructors at the College of Veterinary Medicine design a series of systems-approach intervention materials and assessments to improve student veterinarians’ abilities in problem solving. Design research was conducted for the dissertation study. The specific design and materials varied within this basic structure to meet the requirements of each course. The assessment for this study occurred in successive semesters. At ISU, Fall semester encompasses mid-August to mid-December and spring semester encompasses early January to May. Consistent with design research tradition, lessons learned in the application of the systems approach in prior semesters were applied to introductions used in subsequent semesters.

**Design Research**

Design research is research that goes through an iterative process to “design” a system for accomplishing a goal (Cobb, 2001; Edelson, 2002; Wang & Hannafin, 2005).
Design research involves “a series of approaches, with the intent of producing new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings” (Barab & Squire, 2004, p. 2). A previous research study indicated that the format of design research includes design studies, design experiments, development research, formative research, formative evaluation, and engineering research (van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). The researchers also mentioned that the character of design research can be interventionist, iterative, process-oriented, utility-oriented, or theory oriented. In addition, the characteristics can involve complex problems, integration of design principles with technological affordances, inquiry to refine the learning environment and reveal new design principles, long-term engagement and refinement of research methods, intensive collaboration, and theory construction and problem solution (Bannan-Ritland, 2003; Baumgartner et al., 2003; Kelly, 2003; Reeves, Herrington, & Oliver, 2005).

**Purpose of the Study**

The purpose of this study was to investigate the application of a newly designed systems approach instruction on veterinary medicine students’ ability to utilize systems thinking. Although the systems approach has been successfully used in many educational fields and seems potentially a natural fit, very little is known about whether systems theory can effectively be applied to Veterinary Medicine education.

**Research Questions**

The fundamental research questions of this study focused mainly on determining whether the newly-designed systems approach improved students’ performance on scenario analysis. The research questions were as follows:
Research question 1: Do systems-approach interventions lead to changes in students’ systems thinking?

Research question 2: Do the following variables contribute to changes in students’ systems thinking: qualifying exam (QE) scores, cumulative Veterinary Medicine GPA (CVMGPA) scores, and gender?

There were two parts to this dissertation study. The first part examined the impact of teaching systems thinking on students’ systems-thinking test performance in Veterinary Medicine courses. A pretest–posttest design was used to assess students’ abilities, following systems-approach lectures, to utilize systems thinking in dealing with practical issues that could face veterinarians practicing in the food supply system. It was hypothesized that students would demonstrate a higher level of systems thinking subsequent to instruction than they did prior to instruction.

The second part of the study was designed to examine the impact of teaching systems thinking on students’ overall academic performance in the Veterinary Medicine program. Historical and current data were used to compare the students’ academic performance changes in the program both before and after systems thinking was introduced. The regression equations between students’ entrance score predictors and the previous year Veterinary Medicine GPA for the four cohorts (classes of 2009, 2010, 2011, 2012) and the regression equations for students who were given the systems-thinking lectures (classes of 2013, 2014, 2015) were compared. It was hypothesized that students in the classes of 2013, 2014, and 2015, who were given the systems-thinking lectures, would demonstrate a higher level of academic performance than would students in the classes of 2009, 2010, 2011, 2012.
Summary

This chapter provided an overview of general systems theory and the systems approach and introduced current needs in Veterinary Medicine education and how general systems theory and a systems approach can help educational outcomes. Design research methods and how these methods were developed in the current study were then described. Finally, the problem, purpose, and research questions for the study were presented.
CHAPTER II. LITERATURE REVIEW

Overview

This review first describes the background, theory, and terms of general systems
theory, the systems approach, and systems thinking. It then gives an overview of previous
studies that have investigated the application of general systems theory to different
educational fields. The available research literature on applications of the systems approach
and systems thinking in educational settings and findings is then reviewed. Finally, a
description of suggestions from previous studies that looked at the design of educational
interventions that teach systems thinking is presented and the specific research questions
addressed in this dissertation are discussed.

Background Theory

General Systems Theory

General systems theory is a level of theoretical model-building that is positioned
between the highly generalized constructions of pure mathematics and the specific theories of
specialized disciplines (Boulding, 1956). General systems theory is a continually evolving
body of ideas useful to people in diverse scientific disciplines (von Bertalanffy, 1956). It is a
body of abstract concepts and mathematical techniques that can be applied to analysis and
design over a wide spectrum of physical systems (Zadeh, 1962). “The links between the
theory and the natural universe may be strengthened by extending the rich stockpile of
abstract concepts downward to acquire ever fuller interpretations and insights into physical
phenomena” (Huggins, 1962, p. 3). For example, in engineering education, the links
between the domain of concepts and the natural universe may be strengthened by helping
students to more readily translate a physical situation into a mathematical model or a
mathematical model into a practical design.
When von Bertalanffy (1956) first introduced general system theory in the 1930s, he stated that there is a general tendency towards integration in the various sciences, both natural and social. Such integration seems to be centered in a general theory of systems. Such theory may be an important means for aiming at exact theory in the non-physical fields of science. (p. 4)

Developing unifying principles that run vertically through the universes of individual sciences, general systems theory can lead people closer to the goal of achieving unity of science in scientific education (von Bertalanffy, 1956). Von Bertalanffy (1956) claimed, “A first consequence of the existence of general system properties is the appearance of structural similarities or isomorphies in different fields” (p. 3). Even though the principles governing the behavior of different entities may be intrinsically and widely different, general systems theory is capable of allowing for the transfer of exact definitions of concepts from one field to another and applying the concepts to quantitative analysis.

The intent of general systems theory is to describe the basic properties or behavior of general systems, including mathematical equations, computer specifications, physical analogs, and verbal descriptions (Mesarovic, 1964). General systems theory is based on the assumption that all systems, including man-made, natural, and symbolic systems, have certain characteristics in common (Bowler, 1981). These common characteristics may form the foundation for a new model that allows for the perception of the unity of the universe. For example, people can use previous experiences that have common characteristics to situate themselves and act effectively in a new context. General systems theory is valid for all systems as they relate to the “unity of science” (Kramer & de Smit, 1977). For example,
the concepts of organization, wholeness, directiveness, control, self-regulation, and
differentiation in physics are also applicable to the biological, behavioral, and social sciences
(von Bertalanffy, 1956).

General concepts emphasize the features common to different systems but exclude
the specific aspects of the behavior of any particular system. Abstract statements might
therefore have a broader context but less information regarding the behavior of any particular
system (Mesarovic, 1964). Characteristics not common to all systems provide the terms for
differentiating among types of systems (Bowler, 1981).

General systems theory examines the qualities of various components interacting with
one another within a system and the resulting systems dynamics over time. To understand
the behavior of the parts, the relations between various subordinate and superordinate
systems must be taken into account rather than just summing their behavior (von Bertalanffy,
1950).

Different scholars have concluded that general systems theory includes the elements
of a holistic concept: common characteristics among all systems, interrelationships between
subordinate and superordinate systems, and system dynamics over time. These traits are part
of systems thinking and have been utilized in a systems approach to solve problems
efficiently and effectively. The following section will give a definition of the term “system,”
as used for purposes of this study, before introducing systems thinking and the systems
approach.

A system is organized as a complex set of interrelated entities or elements (von
Bertalanffy, 1956). These elements or interdependent components either directly or
indirectly interact with or relate to one another (Kast & Rosenzweig, 1972). These connected
interdependent components or parts represent properties of the whole, rather than properties of the component parts added together. For example, although water molecules are formed from two units of hydrogen and one unit of oxygen, the taste of water is a function of the substance as a whole and not the taste of each separate element.

Relationships between interdependent components or different disciplines can be bridged by a common language. Greater chances of exchange demolish language barriers and gaps, and differences lie in the relationship to the whole (Angyal, 1969). For example, the letters a, e, m, t combined produce “aemt,” a meaningless combination in English. After re-arranging the letters to form the words “meat” or “team,” they become meaningful.

A large system might have multiple subsystems that depend on one another (Kramer & de Smit, 1977). As an engineering example, a spacecraft includes mechanical facilities, electrical systems, and other components. These facilities and systems rely on one another during operation. The proper functioning of the system as a whole is largely determined by these interrelationships.

Horizontally, the central concept of a system embodies the idea of a set of interconnected elements. Vertically, a large system will typically have multiple subordinate or superordinate systems. Both horizontal and vertical subsystems are included to form a whole system. For example, people may ask horizontal questions such as “How broadly do you cast your net?” and vertical questions such as “How deeply do you drill?” to decide what elements should be included in and excluded from the system model.

**Systems Thinking**

System concepts initially emerged from the study of biological organisms. The systems movement has been an attempt to explore the usefulness of particular concepts in diverse fields. There are three fundamental concepts of systems thinking in the field of
biology: a small system versus large system, layered structure, and communication and control processes. For example, considering the small system versus large system concept, a cell is a small system whereas an extracellular matrix outside the cell is a larger system. As an example of the layered-structure concept, the cell and the extracellular matrix outside the cell have a layered-structure relationship and can interact with one another, e.g., protein molecules can pass through the boundary of the cell wall and move between the two systems. As an example of the communication and control concept, the human body responds to its environment to survive environmental changes through automatic adjustment of body temperature to counterbalance seasonal variations (Checkland, 1999).

Systems thinking is a method of tackling or approaching problems (Kramer & de Smit, 1977). It is a problem-solving technique based on regarding systems as a whole rather than solving one single problem at a time (Senge, 1990). For example, to make a particular chemical product in an industrial plant, the designer must consider not only aspects of the single plant facility, such as individual reactor vessels, heat exchangers, pumps, etc., but also the plant’s overall performance that must be controlled to produce the desired product at the required rate, cost, and purity. Through knowledge of the variability of the starting materials and the possible environmental disturbances to which the process will be subjected, and by adopting an appropriate control strategy for the plant as a whole, it may be possible to automatically manipulate a few variables to produce the desired outcome (Checkland, 1999).

Systems thinking includes both a multidisciplinary and a holistic view of the elements and processes of an event. The adaptive whole is the central image in systems thinking. The first main idea of systems thinking is that reality should be regarded as a whole, or gestalten; the second main idea is that the environment should be regarded as interacting with other
systems as if they are open systems (Kramer & de Smit, 1977). For example, during a development cycle engineers may successfully design or modify a quality product according to users’ needs, with usability and accessibility features that respond to the reality of what users wish to have rather than serving decorative purposes. Other users or changes in the operating environment over time serve as variables that determine how the designer subsequently modifies the features of the product. For example, different countries may have different cultures and customs, and laws and taboos of a society may be adjusted as situations, such as changes in the ruling structure, change. Different designers, such as an architect as opposed to a locksmith or a composer as opposed to a piccolo player, may each visualize their projects as entire systems and design their creations to function as whole entities (Mager, 1970).

In systems thinking, problems can result from phenomena that differ from previous observations (Pierce, 2002). These problems may result from changes over time (Vugh & Hart, 2004) and might represent differences in interaction between a subject and a present real-world situation (O’Connor & McDermott, 1997). Problems or changes that create issues represent only parts of a structure within a system (Richmond, 1992). For example, in organizational management, the perception of incompetent management may be a significant problem because the leadership team is expected to lead change (Pierce, 1997). An organizational leader should consider potential industry changes as part of the organization management system. Both leaders and employees should have periodic training to be prepared for new situations. Another common problem in an organization is disempowerment or closed communication among employees and supervisors. Keeping production operations going despite safety issues may be a problem (Pfeffer, 1996).
Employees at the “back end” of a company may see a better way to make the product line run efficiently and operate safely, whereas those at the “front end” of the company may interact directly with customers and clearly see their needs. Being receptive to employee feedback is important in establishing trust between leaders and employees, thereby leading to improvement in products, service, and the organization itself. Communication and interaction between leaders and employees, empowerment, and prioritizing operating safety should be part of the management system as a whole in order to meet the changing world.

There have been parallel developments in systems thinking in various sciences extending back to the 1920s. In 1923 in the field of psychology, Wertheimer argued against the robot model, which held that behavior is explained by way of a mechanistic stimulus–response model but not through some aspects of human behavior. This led to development of Gestalt psychology in which one proceeds from the whole (Kramer & de Smit, 1977). Being able to see the overall structure of a problem is essential to successfully finding its solution.

A certain region in the field becomes crucial, is focused; but it does not become isolated. A new, deeper structural view of the situation develops, involving changes in functional meaning, the grouping, etc. of the items. Directed by what is required by the structure of a situation for a crucial region, one is led to a reasonable prediction which, like the other parts of the structure, calls for verification, either direct or indirect. Two directions are involved: getting a whole consistent picture, and seeing what the structure of the whole requires for the parts. (Werthiemer, 1959, p. 212)

Between 1925 and 1928, in the field of biology, Bertalanffy (1932) initiated general systems theory by elevating the concepts of molecular biology to organismal biology. In 1925, Whitehead published the theory of organic mechanism in which he stated that
molecules differ in their intrinsic character in accordance with the general organic plans of each situation; however, the molecules may still blindly operate in accordance with to general laws. In the same year, Lotka published the theory of open systems regarding systems interacting with their environments (Kramer & de Smit, 1977). In an open system, elements can enter or leave the system, and system components may be changed when elements shift in or out of the system. The characteristic state of a living organism in a body is an open system that maintains itself by exchanging materials with its environment and by continuously building up and breaking down its components. In the theory of open systems, “an organism is growing as long as assimilation is higher than dissimilation, and a steady state is reached once assimilation and dissimilation become equally high” (Drack, 2009, p. 567). The theory of open systems was then further developed in biology in 1956 via von Bertalanffy’s general systems theory.

In 1929, in the field of physiology, Cannon presented the concept of homeostasis and asserted that a highly developed living being is an open system with many relationships with its surroundings. Changes in external surroundings stimulate reactions in a system, producing internal disturbances. Through automatic adjustments to achieve equilibrium or balance, internal conditions are held constant within the system (Cannon, 1929). The homeostasis of the human body here includes both external environment and internal organic biological reactions as parts of a whole.

In 1929, in the field of physics, Szilard first pointed out the concept of entropy and the relationship between entropy and its opposite effect. Szilard learned that a decrease in entropy takes place when intelligent living beings intervene in a thermodynamic system. For example, intervention by an intelligent being in a thermodynamic system could lead to the
construction of a perpetual motion machine. When intelligent beings make measurements, they make the system behave in a manner distinctly different from the way a mechanical system behaves. On the other hand, the position coordinate of an oscillating pointer is measured by the energy content of a body. This simple inanimate device can achieve the same essential result as would be achieved by the intervention by intelligent beings. A nonliving device in the “biological phenomenon” generates exactly the same quantity of entropy required in the thermodynamics of living beings. This is similar to the concept of systems-oriented thinking that a condition in the field of biology can possibly be applied to the field of physics.

In the field of sociology, many studies have found that social problems, such as traffic congestion and urban planning, can be improved using a holistic approach that emphasizes mainly the interrelationships between individual parts (Kramer & de Smit, 1977). A report for the club of Rome’s project on the predicament of mankind, entitled *The Limits to Growth*, discussed the mutual relationships between social class, population problems, and food problems (Meadows, Meadows, Randers, & Behrens, 1972). In this report, a world model was created to investigate five major trends of global concern: accelerating industrialization, rapid population growth, widespread malnutrition, depletion of nonrenewable resources, and a deteriorating environment. These trends are all interconnected in many ways. The purpose of creating a world model was to improve long-term global problems by understanding the causes of these trends, their interrelationships, and their implications. A holistic approach considering interrelationships between individual parts and feedback loops is an important component of systems thinking.
In the engineering field, after designing an automatic gun-firing control system, Wiener (1948) published research studies on cybernetics that contributed to the concepts and formalization of feedback and homeostasis. In cybernetic systems, concepts of goal-directed behavior, information flow, and dynamic behavior are applied to complex problems. Control theory was developed and applied in applications such as thermostats and auto-piloted rockets (Kramer & de Smit, 1977). Cybernetics was largely adopted from control theory and the concepts of feedback and homeostasis. These concepts share ideas with systems thinking, e.g., the balance between resistance and enforcement activates counteracting feedback. The feedback determines the internal factors that drive the input and output relationships for managing a system and correcting problems.

In engineering systems thinking, engineers must understand eight general cognitive characteristics: (a) the entire system and the big picture, (b) the interconnections and systems synergy, (c) the system from multiple perspectives without getting stuck on minor details, (d) thinking creatively, (e) a new system or concept immediately upon presentation, (f) the implications of proposed change, (g) analogies and parallelism between systems, and (h) limits to growth (Frank, 2006). Because engineers with a high capacity for systems thinking understand the entire system, they recognize each of these functions specifically as part of the entire system and know how to consider the environment in which each should perform. Given changing, multiple, ambiguous, and conflicting alternatives, the inability to precisely define objectives usually makes a situation problematic in the first place (Checkland, 1981).

These engineers understand the interconnections between disparate parts and that those mutual influences among system elements are circular rather than linear, effects usually influence causes, and causes can affect one another. They can identify the synergistic effects
and emergent properties of combined systems not found in the parts of the individual subsystems. They examine the system from multiple perspectives rather than from a single viewpoint and describe a system from all relevant perspectives. Such multiple perspectives include the upper layer of investigation, such as managerial perspectives; the systems layer, such as mechanical perspectives; and the engineering layer, which has the ability to examine a specific problem from different angles and points of view.

Engineers try to develop a tolerance for ambiguity and uncertainty and try to avoid getting sidelined by minutiae so they can continue to act without fully understanding system details while yet seeing the overall picture. Striving for simplification, engineers filter out “noise” such as redundant and unnecessary information. Their thinking is lateral, divergent, and heuristic at the brain-storming stages of a project and logical, convergent, algorithmic, and analytical in its implementation stages. They must include side effects, assess impact, and handle every step of change implementation such as identifying needs and coordinating with all involved departments. They try to instantly achieve a conceptual grasp when a totally new system is introduced. They know how to relate resemblances and infer conclusions with respect to different disciplines. They also take into account factors and processes that balance performance growth (Frank, 2006). For example, when seeking ways to improve the effective output power of a given data transmitter, systems engineers consider not only methods such as increasing amplification, but also others related to factors such as the power supply, antenna, cooling system, and mutual interferences by other systems in the area of deployment.

All these combined systems-thinking concepts lead to the conclusion that multi-disciplinary environments can enhance communication (Boulding, 1956). Systems thinking
leads to descriptions in a common language that can be used by scientists in different disciplines as they communicate with one another. Such communication allows people to more easily adapt to changing environments (Checkland, 1999). In organizational theory, management, marketing, finance, accounting, information systems, and economy are integrated in corporate models to evaluate the behavior of a corporation both as a whole and as its separate parts. Because the goal of a corporation is to grow and make a profit, each department must continuously talk and interact with other departments as well as consider customer or client feedback. After adjusting operations in each department, the corporation can improve its performance and provide better products in order to survive in the changing world.

Systems thinking has adopted some concepts from general systems theory, mostly from the field of biology, and applied them to systems engineering to improve effectiveness, availability, reliability, maintainability, quality, and trustworthiness (Checkland, 1999). Eight systems-thinking skills are included in the systems approach: 10,000-meter thinking, system-as-cause thinking, dynamic thinking, operational thinking, closed-loop thinking, nonlinear thinking, scientific thinking, and empathetic thinking (Richmond, 1992). Four of these eight concepts, 10,000-meter thinking, dynamic thinking, closed-loop thinking, and scientific thinking, were adopted from general systems theory. An overview of Richmond’s (1992) descriptions of these major thinking skills is presented in Table 2.1.

The concept of 10,000-meter thinking allows people to see the big picture by approaching it as if it were a forest seen from an altitude of 10,000 meters in an airplane. The key of such thinking is to understand the whole system horizontally and vertically,
broadly and deeply, and to determine important external forces or inputs affecting the problem.

Dynamic thinking helps people filter out nonessential elements and maintain a nonstatic view of reality by seeing patterns and trends from historical and economic perspectives. Dynamic thinking is an ongoing process; no system is static, although a system may have to be frozen in time to perform a diagnosis. For example, people may change a routine because of some special activity or, conversely, stick to a routine and skip that activity, depending on what matters to them at the moment, over the long term, or based on another activity occurring during the same time period (Baets, 1998).

Closed-loop thinking helps people in three ways. First, it lets them reflect on the feedback and conduct more reliable mental simulations by emphasizing and incorporating real-world situations. Second, it improves the understanding of the interconnections between system components. Third, it provides insight by disclosing the internal factors that drive or impact the input–output relationships necessary for managing the system and correcting problems when necessary. For example, exercising raises an individual’s body temperature, which in turn triggers sweat, which cools the individual back down.

Scientific thinking helps people prove the truth or make predictions by running rigorous mode-simulation practices in steady-state tests. For example, researchers test hypotheses and show data; they might ask participants to reason and interpret the interaction of forces for a weight-pulling task in studying the physics of motion (Pauen, 1996).

System-as-cause thinking helps people understand the main cause of the problem by asking two questions: What structural relationships are involved, and would we have the same or a similar problem if different variables were involved? For example, a slinky’s
Table 2.1

The Eight Major Systems Thinking Skills in the Systems Approach (Richmond, 1992)

<table>
<thead>
<tr>
<th>Thinking skills</th>
<th>Description</th>
<th>Examples</th>
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<tr>
<td>1. Forest (or 10,000 meter)</td>
<td>10,000 meter thinking is the main structure of systems thinking. The key is to understand the whole system horizontally and vertically, broadly and deeply, and to determine important external forces or inputs affecting the problem.</td>
<td>What are important external forces or inputs? What is the boundary? Like a 30,000-foot view from an airplane, 10,000 meter thinking helps one to see the big picture and boundaries. For a veterinary example, when a dairy farmer sees a high frequency of “odd” swine illnesses, the four circles approach to pig health is applied: first, a complete circle walk through the outside of the building/site; second, a complete circle walk through the inside of the building; third, a complete circle evaluation of an individual pen; fourth, a complete circle evaluation of an individual animal.</td>
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<td>thinking</td>
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<td>2. System-as-cause thinking</td>
<td>In system-as-cause thinking, one asks two questions: What structural relationships are involved, and, would one have the same or similar problem even if, e.g., a different infectious agent were involved? Sometimes an object itself is the main cause of the problem, not external forces. The mental model should contain only those elements whose interaction is capable of self-generating the phenomenon of interest. The simplest explanation for a phenomenon is usually the best explanation because too much detail creates vertical bias.</td>
<td>For example, a slinky’s structure is the cause of its own oscillation, not gravity or shifting it between hands. Although removing the supporting hand is an external stimulus, both gravity and removal of the supporting hand are not part of a mental model in this case. For a veterinary example of system-as-cause, pig salmonella prevalence is 5% on-farm and 40% at slaughter. In this case, the percentage of salmonella prevalence is the stock or state variable with a quantity of units. The processes between farm and abattoir are input, output, and flow, representing a change or movement from one state to another. Transportation and lairage are two processes between these two locations. The cause of the problem may be found in these two locations or processes.</td>
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<td>3. Dynamic (or filtering)</td>
<td>Dynamic thinking is a behavioral dimension and ongoing closed-loop process that encourages one to “push back” from historical events and economic points to see the “pattern” and “trends” of which one is a part. One asks what changes have happened or will happen as these processes continue. Dynamic thinking helps one filter out the nonessential elements and maintain a nonstatic view of reality. No system is static, although one often has to “freeze” time to perform diagnosis. One asks, for example, what the problem is TODAY, or how many cows are sick or dead?</td>
<td>What changes have or will happen as this issue continues? One makes decisions based on the situation at the time. There is no set answer. For example, one changes one’s routine because of a special activity, or sticks to the routine and skips the activity depending on what matters at the moment, over the long term, or based on another activity during the same period (Baets, 1998). “The U.S. declared its independence from England on July 4, 1776. Prior to that specific date, tensions built continuously between the two parties to the ensuing conflict. In economics, the focus is on equilibrium points, as opposed to the trajectories that are traced as variables move between the points” (Richmond, 1992).</td>
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<tr>
<td>thinking</td>
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<td>4. Operational thinking</td>
<td>Operational thinking concerns (a) change, such as a shift from susceptible to infectious, infected to immune, sick to dead, unvaccinated to vaccinated, nursing to weaned, uncontaminated to contaminated (e.g., food-borne pathogens on a carcass), tested for infection to known infected; or (b) transformation, such as open to pregnant, milking to dry, live animals to carcasses, carcasses to meat (whole cuts, trim, ground), or meat to human illness with food-borne pathogens. With operational thinking, one can leverage development of horizontal thinking skills, represent the relationships between the elements one decides to include, and know how and when to include delays in stocks and flows. Operational thinking is not a differential diagnosis list. In operational thinking, one asks questions such as how a product is supposed to work and whether the cause-and-effect relationships are producing desirable or non-desirable behaviors. This is different from serial cause-and-effect “laundry list thinking” or “critical success factors thinking.” Similar to the regression analysis $DV = IV1 + IV2 + \ldots$, which is defined by a set of four “meta” (content-transcendent) assumptions that are used to structure cause-and-effect relationships. Causal “factors” operate independently. Causality runs one way, linearly, and unfolds instantaneously or without any significant delay.</td>
<td>Instead of brainstorming “What are all the factors that influence learning,” Richmond (1994) asked a group of educators who were interested in understanding “how to accelerate and enrich learning” to think operationally and “How does learning occur? What is the activity-basis for learning?” The activity-basis for learning is experience, as all members of the group embraced. Seeing the operational picture of the learning process enabled the discussion to proceed efficiently.</td>
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<td>5. Closed-loop (or feedback) thinking</td>
<td>With closed-loop thinking, one asks what internal factors drive or impact the input and output relationships. Counteracting and reinforcing are the two types of feedback loops. Closed-loop thinking helps one understand interconnections and gain insight for managing the system and correcting problems if needed. One also asks, “Can the set of reciprocal relationships that I’ve pieced together in fact generate the behavior patterns that are being produced by the actual system?” Closed-loop thinking helps one to reflect on and conduct more reliable mental simulations. It does so by emphasizing and incorporating real-world situations.</td>
<td>Whenever a noun links back to its original sentence, a feedback loop exists (Richmond, 1992). Oppression breeds resistance, which leads to more oppression under dictatorial government regimes. One experiences resistance when pushing something controlled by a counteracting feedback loop, thereby maintaining balance. For example, exercising raises an individual’s body temperature, which triggers sweating to cool the individual back down. The mushrooming population in the U.S. sunbelt cities is one example of a reinforcing feedback loop.</td>
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Table 2.1 (continued)

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<th></th>
<th>Non-linear thinking</th>
<th>Scientific thinking</th>
<th>Empathic (or generic) thinking</th>
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<td>6.</td>
<td>Non-linear thinking (vehicle or conveyor) to capture the interaction with reality (delay), to anticipate an action’s impact, and to address concerns upon graduation. Non-linear thinking helps one better anticipate and initiate an action’s impact on addressing pressing social and environment concerns upon graduation. In nonlinear thinking, one asks how the strength of input–output relationships will change over time; are there lumps or bumps in the path?</td>
<td>The assumption of linearity means each causal factor impacts the effect by a fixed, proportional magnitude, etc. Instead, the strength of the relationship will change with the magnitude of a third variable. Some veterinary examples are: herd immunity, law of diminishing returns with respect to tuberculosis eradication, bull-to-cow ratio, stocking density and infectious disease, and drug administration.</td>
<td>For example, researchers may show the data and test hypotheses; ask participants to reason and interpret the interaction of forces for a weight-pulling task for the physics of motion (Pauen, 1996).</td>
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<td>7.</td>
<td>Scientific thinking is the collection of sound and rigorous simulation practices that put models into a steady-state condition to test and “idealize test inputs.” In scientific thinking, one asks how one can build confidence versus proving the “truth” or making predictions.</td>
<td>For example, a teacher may use role-playing through real life assignments to engage new contexts for students (Sheridan, 1992).</td>
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<td>8.</td>
<td>Empathic thinking is “a process of reflection whereby people rely on experience, intuition, and feeling to evaluate ideas in relation to their own personal philosophical orientation” (Kristan, 1995). People using empathic thinking can increase clarity of listening and articulation between the stock and flow. Empathic thinking helps one to learn organizational infrastructure and to boost the capacity for both giving and receiving feedback on mental models. For empathic thinking, one asks how this structure and functionality are similar to other systems or experiences; is it a positive (reinforcing) or negative (balancing) feedback loop.</td>
<td>For example, a teacher may use role-playing through real life assignments to engage new contexts for students (Sheridan, 1992).</td>
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</table>
structure, not gravity or shifting it between hands, is the cause of its own oscillation.

Although removing the supporting hand is an external stimulus, both gravity and removal of the supporting hand are not part of a mental model in this case. The mental model should contain only those elements whose interaction is capable of self-generating the phenomenon of interest.

Operational thinking helps people relate changes from one situation to another, to leverage development of horizontal thinking skills, represent relationships between the elements they decide to include, and know how and when to include reality in their mental model. For example, to efficiently engage in a discussion about how students accelerate and enrich learning, educators attending a workshop should ask themselves questions such as: How does learning occur and what is the activity-based learning? The answers to such questions may enable educators to see an operational picture of the learning process.

Nonlinear thinking can help people in three ways by asking two questions: How does the strength of input–output relationships change over time (because the strength of the relationship will change with the magnitude of a third variable) and are there lumps or bumps in the path? The three achievements are: first, to capture the interaction between an object and reality; second, to better anticipate and initiate an action’s impact; third, to address pressing social and environmental concerns.

Empathic thinking helps people learn organizational infrastructure and boost their capacity for both giving and receiving feedback from mental models. In empathic thinking, people may ask how a particular structure and functionality are similar to other systems or experiences, e.g., whether it is a positive (reinforcing) or negative (balancing) feedback loop.
For example, one teacher used role playing through real-life assignments to engage new contexts for students (Sheridan, 1992).

One related idea is that systems thinking integrates the processes of thinking, communication, and learning skills, enabling people to effectively answer the “what to include in the mental model” question (Richmond, 1992). A mental model is a selective abstraction of reality that people create and carry around in their heads (Richmond, 1992). People use such a model to obtain meaning from what they are experiencing and to make decisions. By having all three processes working together, systems thinking helps people map a structure, diagram, or model in their mind when analyzing or evaluating a situation. For example, people have to deal with their job, family, or school, and none of these are physically present inside their head. Instead, when dealing with them in a particular context, people select certain aspects of each that are germane to the context and relate those aspects to one another using some form of cause-and-effect logic. Then people simulate the interplay of these relationships under various “what if” scenarios to draw conclusions about a best course of action or to understand something about an event that has occurred. If a father is trying to understand why his daughter isn’t doing well in arithmetic, he could safely ignore the color of her eyes when selecting aspects of reality to include in the mental model he constructs, because that aspect of reality is unlikely to help him in developing an understanding of the causes of her difficulties or in drawing conclusions about what action to undertake. But, when selecting a garment for her birthday gift, eye color probably ought to be in the particular mental model use in making gift choice. Examples of each of these three processes are presented in the following paragraphs.
For example, in the thinking process, people may gain a big picture view but little vertical detail from seeing a horizontal expanse when looking down from the seat of a jet airliner using 10,000-meter thinking. In system-as-cause thinking, mental models should contain only those elements whose interactions, without any external forces, are capable of generating the phenomenon of interest. Finally, dynamic thinking helps people filter out nonessential elements of reality when constructing a mental model in a behavioral dimension. In general, thinking involves having a thought to reason about, to reflect on, or to ponder. Systems thinking is different from thinking in general in the following way. In systems thinking, the first component of thinking is the construction of mental models, perhaps by creating scenarios, playing, or storytelling. Constructing mental models uses only essential information and simplifications. One approach to helping people develop the ability to construct mental models of systems includes teaching them to use six of the eight systems-thinking skills discussed previously (Richmond, 1992): 10,000 meter, system-as-cause, dynamic, operational, closed-loop, and nonlinear thinking. The second component of thinking is mentally simulating these constructed models via, for example, role playing or cause-and-effect evaluation (Richmond, 1992). Such mental stimulation represents scientific thinking based on the eight systems-thinking skills mentioned earlier in this chapter.

As an example of the communication process, teaching operational and empathetic thinking skills might help people to effectively speak and write a STELLA model’s stock-and-flow common language. STELLA is a simulation application that helps people dynamically visualize and communicate complex systems and ideas, thereby improving their communication capacities in a multidiscipline curriculum. The level of both comfort and confidence in moving freely across disciplinary boundaries also can be improved. Listening,
articulating, and empathizing can boost the capability for both giving and receiving feedback. Operational thinking enables people to effectively answer the “when and how to include the external factors in the mental model” questions. Usually, communication comprises the verbal, written, or physical transmission of meaning between two or more people. In systems thinking, communication is the feedback people provide after scrutinizing one another’s mental models and associated simulation outcomes. In the communication process, empathetic thinking, the eighth systems-thinking skill, improves the capacity for giving and receiving feedback using mental models.

Learning is realizing the impact of one’s actions, an activity that Richmond (1992) called ramifying delays. The amount of learning achieved depends on the quality of the feedback and a willingness and ability to “hear” that feedback. For example, in the learning process, the following 10 steps of capturing the full impact of actions can be stated. First, all possible elements of the mental model are listed. Second, certain elements remain in the mental model after selection. Third, represented elements in the mental model are listed. Fourth, other inspired learning, such as cumulative communication, occurs when a mental model’s content or representation of content is changed. Fifth, outcomes are shown or conclusions are drawn after simulation. Sixth, self-reflection learning occurs, and the loops of the mental model restart from either selecting or representing elements when simulation outcomes are shown. Seventh, when conclusions are drawn, decisions are made. Eighth, actions are taken after decisions are made. Ninth, ramifying occurs after setting chosen actions in motion. Tenth, the full impact of one’s actions is shown.

**Systems Approach**

A systems approach utilizes specific problem-solving techniques from systems thinking, as discussed in the previous section. Systems approach is a holistic approach that
considers the system as a whole, from the outside to the inside, consisting of interdependent elements (Kramer & Smit, 1977). The systems approach is a method for diagnosing and designing solutions to complex problems (Richmond, 1992). Although the systems approach was originally developed mainly to address problems in biology, it has found tremendous application in livestock production, food harvesting, processing, transport, domestic and global policy development, and other fields. The approach involves focusing on physical processes of phenomena, complex interactions between system variables as they change over time, and analysis of the systems’ numerical and qualitative (graphical) solution representations (Allen, 2006).

One of the differences between the traditional and a systems-oriented approach to teaching is that, in the traditional approach, as indicated by Hurd (2009), the instructor uses scientific reductionism, e.g., an animal is a sum of its parts. Hurd (2009) also highlighted that Veterinary Medicine texts treat diseases separately in terms of the physiological areas they affect, such as in the cases of respiratory, alimentary tract, or urogenital diseases. Richmond (1992) believed that, in using the traditional approach, the process by which students obtain knowledge is solitary and nonthinking in nature, involving no constructed mental model or decisions about what to include and how to represent a mental model or simulation nor any requirement or benefit from communication.

Hurd (2009) argued, for example that traditional teaching in Veterinary Medicine leads students to develop only a limited understanding of extra-label drug use (ELDU). Because traditional instruction presents only the legal regulations associated with ELDU and specific examples of the designated dosages for meeting those regulations in veterinary practice, students’ understanding is limited to just memorizing the legal aspects and the
ramifications of misuse. In another example of traditional thinking, neonatal diarrhea in piglets is frequently presented by way of a long list of different diseases, each discussed individually. The general characteristics of the each disease’s causal organism are identified to help students realize the importance of that particular agent. The method by which the agent is transmitted and the suggested treatment options are then provided. Finally, prevention practices particular to this agent are discussed. As a consequence of this teaching approach, students tend to approach problems by dealing with each issue separately. Although this approach may lead to students learning the details of particular disease agents, it doesn’t help them integrate that knowledge into an overall picture of food production (Hurd, 2009).

In contrast, a systems approach to such teaching would consider dynamic and interactive components that present problem scenarios; such scenarios promote diagnostic analysis and intervention decision-making. The systems approach also trains students to ask systems-oriented questions. Such questions would be raised from the viewpoint of the eight previously-stated systems-thinking skills. For example, a question might inquire about information about the relationship between the time occurrence of the problem and its associated location or locations.

The systems approach allows students to better integrate their knowledge into a conceptual understanding of the role they play as veterinarians with respect to food safety and public health. Using the neonatal diarrhea example presented earlier, in the systems-oriented teaching approach the performance problem would be described as follows: “The percentage of pigs with loose stools was above a target goal of x%, with death rates at acceptable levels. Sampling output of the system (ill pigs) revealed infection with two
different agents.” Inputs into the system, such as historical data regarding feed, water, and new pigs, would be reviewed. The students would then be encouraged to analyze the system, in this case located in a nursery barn. This analysis might reveal that holistic concepts such as herd immunity, pig flow, and micro- and macro-environmental impacts, along with an infection agent, are the causes of problem.

The goal of the systems approach is to help students develop a broader understanding of the entire food production picture. Embedding multidisciplinary topics, such as food-animal medicine, production, and food safety, along with systems principles, is an innovative method within the systems approach that assists students to first determine system performance, describing how the system currently functions, including its inputs, outputs, and various intervening processes in the overall environment, and then to indicate just how the performance fails to meet the goals. Over time, students can better manage unexpected situations through such an approach.

**Teaching Systems Thinking: A Literature Review**

Systems thinking has been applied to higher education in fields such as engineering (Frank, Lavy, & Elata, 2003; Raia, 2005), physics, psychology, instructional technology (Barson, 1967; Silber & Foshay, 2009), education (Popham & Baker, 1970), marketing (Lazer, 1966), and management (Bare, 1970; Molenda, 2010). Systems thinking has also been applied to K–12 education in the fields of science (Draper, 2010), mathematics (Dick & Latta, 1970; Frick & Koh, 2007), biotechnology (Dori, Tal, & Tsaushu, 2003), and biology (Assaraf, Dodick, & Tripto, 2013). This section first provides a discussion of the theory of systems thinking with respect to educational fields. Following this is a review of research
literature on systems thinking applied to educational fields in K–12, areas other than Veterinary Medicine in higher education, and finally Veterinary Medicine.

**Theory of Systems Thinking Applied to Educational Fields**

According to previous studies on general systems theory, systems thinking should be used for education (Finn, 1956). For example, the systems concept represented an important solution for the audio-visual (AV) movement, later referred to as instructional technology. Because instructional technology is part of an overall system, including pre-K to college-level educational activities, everything associated with that system had to be developed, studied, or taken into account (Finn, 1956). It was not just developing an AV movement; it was developing a system of instructional technology capable of integration into other systems to create educational efficiency (Finn, 1956).

For example, the director of instruction at a junior college designated a position on the organization chart for an AV director, which required a professional person. However, when the college consultant, a theorist in educational administration, was finished with the organizational chart, he replaced the AV director with an AV technician, basically a projector repairman. By this one simple move, the AV potential of the instructional program was reduced by 100 percent and the classroom efficiency vanished. Ultimately, the AV program of the college did not provide the desired function.

**Research Literature on Systems Thinking Applied to Educational Fields**

This section will begin with the literature related to K–12 and higher education in areas other than Veterinary Medicine. The Veterinary Medicine literature will then be discussed.

**K–12 education.** Some studies have pointed out that including some components as a whole are necessary for students to learn better. For example, in a research study at an
Indiana Montessori elementary school based on a logico-mathematical general systems-theory model, Frick & Koh (2007) applied autonomous supportive strategies to improve student choices over learning activities during a 16-week session. Students were required to complete a number of tasks that included research projects in physical science, natural science, history, and geography; book reports with topics collaboratively chosen by teachers, parents, and students; and workbooks and flash card drills in math. Their results showed that teachers’ instructions and information clarification could improve students’ learning as well as their independent decision making, feedback, interaction, partnership, and teamwork, and their social activities as a whole. By considering the system as a whole, students’ learning choices, teachers’ support styles, and the relationship between these two groups were included to provide an improved solution.

Similarly to that study, students in three Israeli high schools gained an improved understanding of biology with explicit scaffolds providing information or concepts as support (Assaraf et al., 2013). Specifically, students with such support could effectively develop higher level systems thinking on homeostasis and the temporal or hidden dimensions of mechanisms such as gas exchange in the lungs. Students’ ability to synthesize system processes and components, such as connections and junctions, were also increased using concept-map mediation.

Learning activities helped students in the development of both their higher and lower order thinking skills. For example, students’ thinking skills at an Israeli high school improved after exposure to case studies related to scientific controversies such as how science and societal issues, including environmental and moral conflict, affect one another in a whole system (Dori et al., 2003). There was significant improvement at all student levels.
in students’ knowledge and understanding of concepts with respect to both lower order thinking skills and general higher order thinking skills.

In a related study, students at another Israeli high school viewed the entire system beyond component boundaries and understood the interaction between system components after attending a 3-year electro-optics program with a newly designed curriculum (Gero & Zach, 2013). This curriculum integrated engineering principles into the teaching of physics, and thereby developed improvement in students’ systems thinking skills. At the end of 12th grade, students were asked to complete a comprehensive final project that included content knowledge taught in the 3-year program. For example, one group of students created an electro-optical system for their final project. In this system, security forces could be directed to a specific location when an intruder made contact with a security fence powered by solar panels. Similarly, after establishing teacher–student mentor or apprentice relationships at an Arizona high school science class, students reconsidered how the world works using a new paradigm that helped these students’ deep-systems thinking and continued learning (Draper, 2010). Specifically, thinking skills, such as feedback, dynamic, scientific, operational, and generic thinking, were demonstrated through real-world problem solving as well as through teacher–student interaction. The instructor had encountered problems in teaching and learning in his own U.S. high school science class and suggested solutions for improvement through the use of systems thinking, which treated the curriculum as a whole.

In another case, both students and teachers in two California middle schools demonstrated the ability to recognize common patterns across natural and social settings through systems-thinking perceptions (Sweeney & Sterman, 2007). A systems-based inquiry protocol including six scenarios was developed and tested to examine both student and
teacher understanding of the key elements of dynamic complexity. They were able to
demonstrate homological reasoning skills, recognizing recurrent patterns of behavior in
different domains, across subjects and disciplines, within a wide variety of systems.

For example, in the wolf–rabbit scenario in the study, it was known that the
population of wolves and rabbits, which relies on the predator–prey relationship, changes
over time. When asked how this scenario might be similar to another scenario in a different
setting, both teachers and students were able to relate balancing feedback scenarios such as
hunger/eating and room clean-up/parents’ attitude. A hunger and eating scenario links
balancing feedback and goal-seeking behavior: as hunger increases, one eats; then hunger
decreases. The room clean-up/parents’ attitude scenario considers the relationship between
the state of a room (clean or dirty) and the attitude of parents (happy or upset), which forms a
balancing feedback configuration.

Although most teachers’ understanding of how dynamic systems function is better
than that of their students, both groups had limited intuitive systems-thinking abilities; they
exhibited poor understanding of the key elements of dynamic complexity, including a lack of
awareness of dynamics, feedback processes, time horizons, and accumulations; they also had
misconceptions with respect to stock and flow structures and little ability to expand the
boundaries of their mental model or to increase the range of feedback components and
considered factors.

One study, utilizing Sweeney and Sterman’s (2007) predator–prey activity, involved
424 sixth-grade students from six secondary schools in Germany who showed significant
improvement on their achievement scores from the pretest to the posttest (Riess & Mischo,
2010). They received a combination of lectures and an ecosystem forest scenario computer
simulation game in a biology course. The game included 15-year forecasting on planting trees, employing lumberjacks and harvesters, buildings fences, supplying wood, financing budget, groundwater quality, biodiversity, and possible storms or pending damage caused by animals. The instructional tools included cause-and-effect diagrams, dynamic processes of systems, simulations, real-world cases such as a worm farm process, and predator–prey relationships.

In a related study in three Israeli high schools, students demonstrated a lack of ability to characterize hierarchy, homeostasis, and dynamism—the three basic patterns of the human body system (Assaraf et al., 2013). They were unable to identify interactions between components, between systems, between a person and her or his environment, or throughout the system as a whole to comprehend biological dynamism.

In separate research focused on a Florida eighth grade mathematics class, students’ overall performance in learning systems thinking for the programmed instruction group using the paper method was significantly better than the computer-assisted instruction group using computer methodology, although there was no difference between the two instructional methods for students with higher GPAs (Dick & Latta, 1970). Students tended to prefer a memory aid, such as a hard-copy printout, to use during the immediate learning session or later for review. Both methods included the same materials developed using a systems approach, including revising instructions based upon feedback from several student evaluations, one-on-one field testing followed by revision, and extended field testing.

In summary, although students and instructors at the K–12 level had some intrinsic thinking skills, most of them lacked the perception and understanding associated with systems thinking, regardless of their GPA, gender, parents’ educational background, or
curriculum emphasizing ecosystems (Dori et al., 2003; Sweeney & Sterman, 2007). For example, in the study of two California middle schools, both students and teachers had a weak understanding of the concepts and key elements of dynamic complexity, including dynamics, feedback processes, time horizons, and accumulations (Sweeney & Sterman, 2007). They incorrectly assumed that feedback exists in an open loop or exhibits one-way causality. In addition, they tended not to describe factors outside the immediate boundary described by the elements of the scenario. Another example in the study of an Israel high school biotechnology class showed that students were incapable of completing higher order thinking skill (i.e., systems thinking) assignments. They were unable to explain how science and society affect one another (Dori et al., 2003). However, students showed improvement on their achievement scores after receiving a combination course that included lectures and a computer simulation game (Riess & Mischo, 2010). Students need systems-thinking support, and instructors need to understand it beforehand as well. Students particularly benefited from teacher interaction and mentoring based on real cases.

**Higher education.** Concepts of systems education were brought to the University of Southern California by Finn in 1956 (Molenda, 2010). Later at the same school, in 1963, systems-engineering concepts were introduced by Silvern in a designing instructional systems course in the Department of Instructional Technology. In 1967, Barson presented systems theory in formal and nonformal education and training in an instructional systems development project at Michigan State University. Collaborating institutes, including Syracuse University, the University of Colorado, and San Francisco State College, also applied a systems approach to actual course development (Barson, 1967). These four universities cooperated with the instructional media center at Michigan State University to
test, demonstrate, and refine a model for media innovation and instructional development, with media, evaluative, and instructional specialists working together to develop the teaching materials to be used by instructors. The procedural model later became the central component of the instructional systems design model (Molenda, 2010). At the same time, Lazer (1966) foresaw systems thinking as a trend in marketing education. He believed the systems approach would affect future marketing knowledge by modeling and analyzing complex systems by emphasizing the integration of elements of networks, linkages, interactions, feedback, system adjustment, and growth into a whole system.

Most experimental studies in higher education have been directed toward determining students’ understanding of systems thinking. Students attending the City College of New York conceptualized dynamic systems in landmark or static views in an earth science and engineering class (Raia, 2005). They did not take a planet’s temporal and spatial scales into account, and they explained complex natural phenomena in earth processes either as due to a single causal force or as a linear chain of unique causal forces. These problems might be resolved by a course design that embodies systems thinking and hands-on activities.

For example, students at an Israeli college developed their engineering thinking and their intuition in a systems-thinking paradigm-based course in mechanical engineering (Frank et al., 2003). Students acquired knowledge from both interdisciplinary and multidisciplinary fields and gained skills from engineering design, problem solving, information retrieval, and identifying the relationships between the elements of the constructed product.

In a similar study, students who played a forest management game in a forest financial management course at Purdue University were able to review, resynthesize, observe, and apply biological and financial concepts and factors previously studied and
associated with operational forest management to a specific management problem (Bare, 1970). The systems-analysis approach helped students visualize interrelationships between the biological and financial components of the forest system and to visualize the operational problems of the forest manager from a total-system point of view. In addition, students improved their understanding of annual budgeting and gained experiences in making decisions within a management-oriented environment. They became enthusiastic and were highly motivated to perform well in the game. As an educational tool, the management game provided a dynamic systems-oriented environment and competitive process that allowed students to obtain rapid feedback with respect to decision results and to learn team organization, control, communication, and the importance of setting goals and long-range plans.

Furthermore, in a pilot study, rich-picture-based activities improved 17 engineering students’ cognitive development in systems thinking (Vanasupa, Rogers, & Chen, 2008). The activities included behavior over time and causal loop diagrams that helped students consider factors “outside of the box,” which is a precursor to systems thinking. In a related study, not only rich pictures, but also causal loop diagrams and a chart of the behavior of key variables in a system over time, were utilized. These three techniques used together successfully improved students’ systems-thinking skills (Rehmann, Rover, Laingen, Mickelson, & Brumm, 2011). This study was conducted in an ISU engineering program that focused on four pillar areas (leadership, innovation, global awareness, and systems thinking). These four areas helped 21 students consider the range of issues affecting an engineering problem. However, the study also showed that students were struggling with identifying key variables and deriving behavior over time from a causal loop diagram.
Moreover, a study in an inquiry-oriented differential equations class at a midwestern university developed and used parametric reasoning, allowing time for students to understand dynamical systems of differential equations (Allen, 2006). Students developed their understanding of systems of differential equations through dynamic visualization, real-world scenarios, graphical symbolizations, prior knowledge, context, and algebra. The instructor used generative alternative pedagogy instruction of recovering solutions of single differential equations that emphasized graphical, numerical, and analytical techniques, assignments such as reflection journals and portfolios, small group discussions, and the Nucalc application to help 11 mathematics and engineering students build their conceptions of time and rate. The generative alternative pedagogy presented an idea, solution, or argument for the purpose of encouraging students to make sense of the mathematics either collectively or individually. The portfolios contained self-selected work, such as homework assignments or classroom tasks that best expressed the new conceptualizations they had developed in the first and second halves of the semester. Nevertheless, without the answer to each problem discussed in the class being disclosed, some students showed anxiety regarding the inquiry-oriented instruction, whereas others felt they had not learned anything.

In summary, most students in higher education had static views on dynamic systems (Raia, 2005), although a systems-thinking, paradigm based course helped students develop their engineering thinking (Frank et al., 2003). However, students in an engineering program were able to address factors within and outside of engineering and connections between elements after working on a project that included a causal relationship diagram and a time chart (Rehmann et al., 2011; Vanasupa et al., 2008). In addition, students developed their understanding of systems of differential equations through dynamic visualization; real-world
scenarios; graphical symbolizations; and reasoning of prior knowledge, context, and algebra (Allen, 2006). Furthermore, a game-comprising course using a systems-analysis approach helped students visualize the problems of forest financial management from a big-picture perspective while simulating all related activities as a whole (Bare, 1970). Students in that course not only learned the concepts underlying systems thinking but also gained interest in investigating further. Instructional design has played an important role in delivering a message about the importance of systems concepts in higher education.

**Veterinary Medicine education.** Instructors in veterinary education should consider new collaborative technologies to deliver their teaching materials (Bernardo, 2006). Examples of success in this regard include creative methods, such as a core clinical-learning experience in population health and public practice or specialty training programs developed by regional or national partnerships of colleges, in the curriculum of Veterinary Medicine colleges (Hoblet, Maccabe, & Heider, 2003). Faculty in colleges of Veterinary Medicine should adopt a systems-thinking framework to effect such changes in a creative way (Hurd, 2011).

A group of veterinarians approached the topic of salmonella contamination in pork products from a systems perspective and found that transport and holding processes were two of the main contamination contributors (Dickson, Hurd, & Rostagno, 2002; Hurd, Gailey, & Rostogno, 2001; Hurd, McKean, Griffith, Wesley, & Rostagno 2002; Hurd, McKean, Wesley, & Karriker, 2001). Later, a computer simulation model was developed to answer an important policy question regarding choosing the best point for controlling Salmonella in a pork production system by looking at inputs and outputs (Hurd et al, 2008). This systems approach has been useful in directing U.S. pork preharvest efforts.
One research study found that Veterinary Medicine students conceptualized complex mechanical features, specifically the heart blood vessels in cardiovascular systems, in static anatomical terms, such as the surface structure. On the other hand, cardiovascular research experts integrated deep structure and conceptualized system relations with dynamics that distinguished between relationships involving only system properties and those involving system variables (Hopkins, Campbell, & Peterson, 1987). In this study, 13 second-year Veterinary Medicine students, during their free time, voluntarily filled out a questionnaire concerning relationships among six properties and 11 variables. Students were told that their subjective perceptions and understandings, rather than whether the answers were right or wrong, were the main interest of this study, and that they should be able to complete the questionnaire in 1 hour.

System representations were derived from students’ predictability judgments. The predictability judgments were based on three different techniques: multidimensional scaling, agglomerative hierarchical clustering, and elementary digraph notions from graph theory and structural modeling. These techniques represented perceived relationships among system variables and properties. Multidimensional scaling techniques were used to study conceptual relationships and memory representation. Cluster analysis was used to describe the grouping of entities and to provide a supplement to multidimensional scaling. The hierarchical clustering used in the clustering algorithm was based on average linkages. The semantic distances derived from geometric models were used as predictors of performance with respect to judgment and reasoning tasks. Notions from graph theory were used to understand complex systems.
In section 1, students were asked to rate the predictability of the value of each entity on the list using a nine-point scale, ranging from 1 (not predictable) to 9 (predictable). In section 2, they were asked to rate each of 17 variables and properties on eight 9-point bipolar rating scales. The six properties were: total peripheral resistance, venous compliance, inotropic state (left ventricle), inotropic state (right ventricle), pulmonary vascular resistance, and blood volume. The 11 variables were: heart rate, cardiac output, stroke volume, mean arterial pressure, systolic arterial pressure, diastolic arterial pressure, left-ventricular end diastolic volume, left-ventricular end systolic volume, mean pulmonary artery pressure, mean pulmonary capillary wedge pressure, and mean central venous pressure.

The first four rating scales concerning anatomic characteristics were: related versus not related to lung circulation, related versus not related to systemic circulation, associated versus not associated with heart function, and associated versus not associated with blood vessels. The remaining four bipolar scales concerned with dynamic or system-wide characteristics were: measurable versus inferred, reflects state of entire system versus reflects isolated characteristics, changes slowly versus rapidly, and independent of all other system characteristics versus strongly dependent on all other system characteristics.

The findings showed that the expert was able to distinguish the properties and variables of the cardiovascular system for one dimension related to dynamic system-wide characteristics and for another dimension separating the high- and low-pressure sides of the heart blood vessel loop. Making a distinction between properties and variables is fundamental to the understanding of dynamic systems, but students were not able to do so. For the research methods, multidimensional scaling and clustering techniques could help students in exploring the overall characteristics; this is important for individuals to be able to
form perceptions and conceptualizations of complex systems. In addition, the digraph technique was the simplest form for interpreting the raw data. The simplicity and clarity of the digraph representation provided specific characteristics of perceived system relations. Digraphs are useful in generating and testing research hypotheses and in guiding the instructional process, which makes it easy for the instructor to communicate with a variety of audiences.

The results suggest that educators should emphasize teaching that includes generalized systems concepts of properties and variables and solving problems involving complex systems. Veterinary Medicine students need to learn how to distinguish between system properties and system variables and how to organize and integrate physiologic problem-solving tasks in their future practices.

**Implications of the Literature Review for Design of Educational Interventions Teaching Systems Thinking**

Most educational research studies that investigated systems thinking were performed in the fields of engineering, psychology, and biology; very few came from Veterinary Medicine. The findings from the literature review showed that systems’ structural configurations impacted elementary students’ autonomy choices during social time as a team in a free-flowing work system, instructors’ instructional activities, and instructors’ support through clarification (Frick & Koh, 2007).

Both students and teachers in the middle schools exhibited one-way causal thinking and demonstrated proficient homological reasoning skills (Sweeney & Sterman, 2007). However, they exhibited limited intuitive systems-thinking abilities and lacked perception of systems thinking, independent of their GPA, gender, parents’ educational background, and curriculum that emphasized ecosystems (Dori et al., 2003; Sweeney & Sterman, 2007). They
incorrectly assumed that feedback exists in an open-loop or exhibits one-way causality. For example, in a wolf–rabbit scenario, some students only indicated that wolves eat rabbits. With this response, because feedback does not exist in an open-loop or in one-way causality, the wolf and rabbit’s balancing and reinforcing feedback relationships were not included.

High school students with high GPAs were better able to assess the difficulty of the assignment and respond to elements they could successfully complete, although their argumentation abilities was better than their systems-thinking abilities (Dori et al., 2003). In general, students were aware of the system components of the biological system but not the manner in which such parts interact within that system (Assaraf et al., 2013). Students were incapable of achieving a higher level of systems thinking, e.g., homeostasis and dynamism, in the systems-thinking hierarchy model. They preferred to identify structural components rather than processes of the human body.

Similarly, undergraduate students conceptualized dynamic systems from a static point of view (Raia, 2005). They explained complex natural phenomena in earth processes by a single causal force. In addition, Veterinary Medicine students also conceptualized complex mechanical features in static anatomical terms (Hopkins et al., 1987). They were unable to distinguish between the properties and the variables of the cardiovascular system, in one dimension related to dynamic system-wide characteristics and, in another dimension separating the high- and low-pressure sides of the heart and blood vessel loop.

Although students from K–12 to higher education exhibited limited systems-thinking capacity for problem solving, some studies found that new curriculum design and knowledge supports increased systems-thinking capability. For example, students learned scientific and dynamic thinking from evidence-based real-world phenomenon using STELLA simulation
models for science problem solving (Draper, 2010). Students reconsidered how the world works in a new paradigm while confronting what they previously thought they knew with new information. In addition, students developed their engineering thinking and intuition in a project-based learning approach course situated within the systems-thinking paradigm (Frank et al., 2003). Furthermore, students visualized the problems of forest financial management from a big-picture perspective while simulating all related activities as a whole (Bare, 1970). They utilized a systems-analysis approach and integrated previous course knowledge into a forest management game. Real-world case studies and hands-on multi-disciplinary projects helped improve students’ knowledge and understanding of concepts in systems thinking (Dori et al., 2003; Gero & Zach, 2013).

Several studies emphasized encouraging interaction between instructors and students about real world cases as a way of improving systems thinking (e.g. Allen, 2006; Bare, 1970; Dori et al., 2003; Draper, 2010; Gero & Zach, 2013; Frank et al., 2003). Therefore, the present research included simulations of current swine and goat problem scenarios intended to promoted students-instructors interactions during the demonstrations in the class. For deep systems thinking and continuing education, teachers and students must enter into a mentor/apprentice relationship (Draper, 2010). All thinking skills must be demonstrated through real-case problem-solving with the teacher interacting with the students and not just topics being superficially covered in a regular lesson. For example, as previously noted, a forest financial-management game provided a dynamic systems-oriented environment and competitive process that allowed students to obtain rapid feedback on decision making (Bare, 1970).
In addition, more efforts should be invested in scaffolding systems learning (Assaraf et al., 2013). Students must perceive interactions throughout a system as a whole to comprehend its dynamic properties. Instructors should substitute the phrase “caused by” with “emerges from” when explaining or investigating phenomena so that students concentrate on the components and their interactions and view a phenomenon as an emergent property (Raia, 2005).

The literature also suggests that instructors should provide clear instruction, clarify information, and provide opportunities for students to contribute ideas and suggestions for improving the learning content with which they are working (Assaraf et al., 2013; Frick & Koh, 2007). Educators should develop a curriculum that exposes students to scientific controversies through case studies having environmental and moral implications (Dori et al., 2003). Furthermore, Veterinary Medicine educators should emphasize teaching that includes generalized concepts of system properties and related variables and solving problems based on complex systems (Hopkins et al., 1987). Moreover, identifying key variables and deriving behavior over time from a causal loop should be included (Rehmann et al., 2011).

On the other hand, instructors should consult with professional educators before implementing newly designed approaches to performing the roles of facilitator, mentor, tutor, and mediator, in addition to conveying information or providing facts (Frank et al., 2003). Complex modeling tools such as STELLA, NetLogo, and Swarm offer promising opportunities for systems-based teaching and learning (Draper, 2010; Raia, 2005).

In summary, students need support in applying systems-thinking to problem-solving, and instructors must understand systems thinking and how to support students (Sweeney & Sterman, 2007). Students have especially benefited from teacher interaction using real cases
(Allen, 2006; Draper, 2010). In Veterinary Medicine education, students should learn how to distinguish between system properties and related variables, because such knowledge is fundamental to the understanding of complex dynamic systems (Hopkins et al., 1987).

Based on previous studies, a systems approach was embedded into the Veterinary Medicine curriculum and instructional design described in this study. In this dissertation study, four real-case scenarios and STELLA simulation models were created through the work of three collaborating universities for intervening and assessing students’ understanding of systems thinking. Veterinary Medicine instructors were first trained by systems’ trainers and consultants. Students were asked to analyze the scenarios and select the systems diagnostic questions on problem solving. The purpose of this study was to determine whether students’ ability in systems thinking is increased through using a systems approach.

**Research Questions and Hypotheses/Predictions**

Veterinary Medicine instructors typically use scientific reductionism in teaching, i.e., an animal is a sum of its parts (Hurd, 2009). Each production system is taught individually. As a result, a majority of veterinary students lack a big-picture view of the global food-safety environment, and this was the subject of investigation for this study. Although previous research has described new course curricula and activities able to increase students systems thinking in K–12 and even college instruction, it is not clear whether a systems-approach-based course design would have a direct effect on Veterinary Medicine students’ systems thinking with respect to problem solving. The following general research questions guided the study:

Research question 1: Do systems-approach interventions lead to changes in students’ systems thinking?
Research question 2: Do the following variables contribute to students’ use of systems thinking: qualifying exam (QE) scores, cumulative Veterinary Medicine GPA (CVMGPA) scores, and gender?

The main research question of this study (research question 1) focused mainly on determining whether newly designed systems-approach courses and instructional materials improve students’ performance on analysis of veterinary case scenarios.

This dissertation study involved a partial evaluation of a longer-term design research project implementing systems thinking in Veterinary Medicine courses at ISU and Kansas State University (KSU). In that project, systems-thinking interventions were designed to be blended into courses in the Veterinary Medicine curriculum. A design research process was used, by which each implementation was evaluated and insights from the evaluation were used to inform subsequent implementations. The research conducted for this dissertation involved design research for the first implementation of systems thinking in the Veterinary Medicine curriculum at ISU.

There were two major parts to this dissertation study the methodology of which is explained more fully in Chapter 3. The first part of the study examined the impact of teaching systems thinking in the swine portion of the VDPAM 445 – Large Animal Clinical Medicine course at ISU. A pretest–posttest design was used to assess the impact on students’ abilities to utilize systems thinking in dealing with practical issues that could face veterinarians practicing in the food-supply system.

For this pretest–posttest study, it was hypothesized that students would demonstrate a higher level of systems thinking subsequent to instruction compared to prior to instruction. More specifically, it was predicted that students would obtain a higher mean score on the
posttest than on the pretest. A number of scenarios and question items were created to measure students’ systems-thinking levels. Students were determined to have performed at a higher level of systems thinking when they selected more systems-thinking questions items for diagnosing Veterinary Medicine scenarios.

The second part of the dissertation study was designed to examine the impact of teaching-systems thinking on students’ overall performance in the Veterinary Medicine program. If introducing an educational change led to deterioration in students’ performance in the overall program, questions would naturally be raised about the educational change. This part of the dissertation study used historical and current data to compare the performance of students in the program before the systems-thinking change was introduced with their performance after systems thinking was introduced. The full methodology is presented in Chapter 3. Essentially, in this part of the research regression results, between entrance-score predictors and GPA for the four cohorts (classes of 2009, 2010, 2011, 2012) prior to and after the swine course, that is immediately prior and after to the introduction of systems thinking, were to be examined and compared those regression results for students in the Class of 2013, the first class to receive the systems-approach intervention. Because no strong theory existed for predicting the impact of a systems-approach intervention on overall performance, this analysis would address the research question asking whether the regression equations prior to intervention were different from the regression equations subsequent to introduction of the intervention.

**Summary**

This literature review first provided a description of the background, theory, and terms of general systems theory, the systems approach, and systems thinking. Next, an
overview of previous studies, including a discussion of the application of general systems
theory to different educational fields, was presented. The available research literature on
applications of a systems approach and systems thinking in K–12, higher education, and
Veterinary Medicine educational settings and findings was then reviewed. Finally,
suggestions and implications from a previous study on the design of educational
interventions that teach systems thinking, as well as the specific research questions guiding
this dissertation study, were discussed.
CHAPTER III. RESEARCH CONTEXT AND GENERAL METHODOLOGY

This chapter first introduces the general context of the dissertation research. The research questions and the general methods used to conduct design research (design experiments) are then discussed. Following this general description of the current design research, specific detailed descriptions of the methodology for each of the three experiments is provided. The information provided for each experiment includes the specific research design, participants, instruments, and procedure. Statistical analysis procedures are presented. Finally a summary of the chapter is provided.

Context of the Dissertation Research: Design Experiment

The context for this research was a design research project introducing the systems approach to Veterinary Medicine students enrolled in the curriculum of a major U.S. veterinary college. Design research is research that uses an iterative process to “design” a system for accomplishing a goal (Cobb, 2001; Edelson, 2002; Wang & Hannafin, 2005). The iterations are variations of the design based upon assessments collected during prior steps. In the present educational case, the system was the changed curriculum as implemented, the assessments were pre- and posttests and interviews, and the goal was to produce Veterinary Medicine students who can apply systems thinking to their profession.

Design research involves “a series of approaches, with the intent of producing new theories, artifacts, and practices that account for and potentially impact learning and teaching in naturalistic settings” (Barab & Squire, 2004, p. 2). A previous research study had indicated that the format of design research includes design studies, design experiments, development/developmental research, formative research, formative evaluation, and

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2Although the overall funded design research project includes three universities, this dissertation focuses on only one of the universities.
engineering research (van den Akker et al., 2006). That study also identified that the character of design research can be interventionist, iterative, process oriented, utility oriented, or theory oriented. The design research in this study was intended to determine whether students showed greater levels of systems thinking following intervention than prior to intervention and, additionally, to obtain information regarding both students and instructors to improve the quality of the intervention.

This dissertation study focused on research conducted in two course offerings in the Veterinary Medicine curriculum. The first course was VDPAM 445 – Large Animal Clinical Medicine, taken by class of 2013 students and offered during the Spring 2012 semester. The second course, offered during the Fall 2012 semester, was VDPAM 419x – Advanced Swine Production Informatics, taken by students in the class of 2014 and class of 2015 students. The third course, VDPAM 445 – Large Animal Clinical Medicine, was the same as the VDPAM 445 course offered in the Spring of 2013, but was taken by class of 2014 students during the Spring 2013 semesters. VDPAM 445 covered identical topics during the Spring 2012 and 2013 semesters: The first two thirds of the course focused on diseases and clinical medicine for goat, swine, and cow, and the remaining third focused on swine clinical medicine. However, during the Spring 2012 semester, the systems-approach intervention was implemented only during the last one third of the course that focused on swine, whereas in the Spring 2013 version of the course, systems-approach interventions were included in both the goat and swine portions. VDPAM 419x focused on evaluating the validity of information and data used by swine production companies and recommended software and information systems. Each course had different participants, instructors, instruments, interventions, scenarios, data collection procedures, and research design; the labels Design
Experiment 1, Design Experiment 2, and Design Experiment 3 are used to refer to the Spring 2012 VDPAM 445 course, the Fall 2012 VDPAM 419x course, and the Spring 2013 VDPAM 445 course, respectively.

The collaborating faculty of the Veterinary Medicine core food-animal courses at ISU offered two to four lectures, depending on the instructor that incorporated systems-approach content. The goal of the new curricular approach was to modify portions of the existing course materials using case scenarios and to deliver the same technical information in the context of a systems approach. For example, the instructor could explain the swine model while using the systems approach for problem solving. Veterinary Medicine students experiencing such systems-approach instruction would be expected to employ this new way of thinking in their future internship experiences with, for instance the Food and Drug Administration (FDA) or the Food Safety and Inspection Service (FSIS), and in their practice. To introduce the systems approach in a meaningful context, the instructional designers suggested that the instructors create realistic teaching scenarios based on real Veterinary Medicine cases that had occurred during the preceding 10 years.

A case scenario consisted of one problem along with a list of possible diagnostic questions related to that problem. The instructors revised portions of their existing materials based on such scenarios and used systems-approach diagnostic questions for students’ problem solving. The instructors then listed for each such scenario approximately 20 diagnostic questions that veterinarians could be expected to ask. Afterward, the systems trainers discussed these diagnostic questions with the instructors to determine which diagnostic questions were formed conforming to the principles of systems thinking. Finally, the instructors integrated the scenarios and systems models into the course materials.
One example of a scenario created by the Veterinary Medicine instructors was the swine scenario, which described a 2,400 farrow-to-wean sow operation in the midst of replacing the females (herd rollover) with a new genetic line to improve its grow–finish performance and overall herd health. Following the scenario description, some background was provided, including the fact that a new genetic line of females had been arriving at the farm during the previous 8 months. The farmer was currently concerned about the high number of scouring piglets produced during farrowing.

The diagnostic questions included both systems-approach and non-systems-approach questions. An example of a systems-approach diagnostic question might be “Currently, what is the average percentage of piglets that are affected with scours?” This is considered a systems diagnostic question because it prompts the veterinarian to consider information about the relationship between important management decisions and the overall transition from the state of being susceptible to becoming infected. As a systems diagnostic question it leads one to determine how many pigs belong in each “box” of the “production system flow.” In contrast, the diagnostic question “What is the pH of the scours?” is considered a non-systems diagnostic question in that it does not provide information useful to categorize pigs as susceptible, exposed, or infected or provide information on the possible outcome (not exposed, subclinical, recovered, or death).

The overarching funded project provided the context in which the dissertation study was embedded. An overview of the planned and accomplished timeline for the entire *Food Systems Veterinary Medicine for the 21st Century* funded project as a whole is presented in

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3 Scouring piglets is baby pigs less than 8 weeks old having diarrhea that caused by swine intestinal disease, which can affected by at least 16 different etiologic agents, including bacteria, viruses, and parasites” (Harris, 2013, Overview of Intestinal Diseases in Pigs. http://www.merckvetmanual.com/mvm/index.jsp?cfile=htm/bc/22300.htm)
Table 3.1. The highlighted items indicate the components included in this dissertation study.

Table 3.1

*Sequence of Events in the Overall Design Research Project*

<table>
<thead>
<tr>
<th>Date/time span</th>
<th>Project activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year 1</strong></td>
<td>Project development and materials preparation</td>
</tr>
<tr>
<td>Oct. 25, 2010</td>
<td>1st conference meeting: introducing team and discussing timeline</td>
</tr>
<tr>
<td>Nov. 17, 2010</td>
<td>2nd conference meeting: introducing systems thinking</td>
</tr>
<tr>
<td>Dec. 13, 2010</td>
<td>3rd conference meeting: discussing systems thinking</td>
</tr>
<tr>
<td>Jan. 27, 2011</td>
<td>4th conference meeting: discussing instructional design</td>
</tr>
<tr>
<td>Feb. 24, 2011</td>
<td>5th conference meeting: discussing matters for a 2-day on-site seminar in Ames, Iowa</td>
</tr>
<tr>
<td>Mar. 23, 2011</td>
<td>6th conference meeting: listing courses to be modified</td>
</tr>
<tr>
<td>Apr. 25–26, 2011</td>
<td>Higher Education Challenge (HEC) 2-day seminar: systems-thinking training</td>
</tr>
<tr>
<td>May 19, 2011</td>
<td>7th conference meeting: discussing courses to be modified in each school</td>
</tr>
<tr>
<td>June 2, 2011</td>
<td>8th conference meeting: preparing case scenarios titles and areas for intervention</td>
</tr>
<tr>
<td>July 25, 2011</td>
<td>9th conference meeting: discussing the titles and areas of case scenarios</td>
</tr>
<tr>
<td><strong>Year 2</strong></td>
<td>Materials preparation and implementation</td>
</tr>
<tr>
<td></td>
<td>1. In the swine part of VDPAM 445, Large-Animal Clinical Medicine course at ISU (Spring 2012)</td>
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<tr>
<td></td>
<td>2. Beef scenario at KSU (Spring, 2012)</td>
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<tr>
<td></td>
<td>3. Food safety course at ISU (Summer 2012)</td>
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<tr>
<td></td>
<td>4. VDPAM 419x, Advanced Swine Production Informatics course at ISU (Fall, 2012)</td>
</tr>
<tr>
<td></td>
<td>5. In both swine &amp; goat parts of VDPAM 445, Large-Animal Clinical Medicine course at ISU (Spring 2013)</td>
</tr>
<tr>
<td>Jan. 18, 2012– May 6, 2012</td>
<td>Study 1. VDPAM 445, Large Animal Clinical Medicine Course (Spring, 2012): The instructor embedded the swine scenario in two 1-hour intervention sessions in the required VDPAM 445 course at ISU. Students were given pre-/posttests before/after intervention.</td>
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<tr>
<td></td>
<td>Embedded calf-cow scenario in two classes at KSU.</td>
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<tr>
<td>May 7, 2012– May 31, 2012</td>
<td>Food-safety course at ISU (Summer 2012): Pre-/posttests food-safety scenario without intervention in a food-safety class at ISU.</td>
</tr>
<tr>
<td>May 16, 2012– July 17, 2012</td>
<td>The systems trainers discussing and finalizing the goat hair-loss scenario with the instructor of VDPAM 445 at ISU.</td>
</tr>
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</table>
Table 3.1 (continued)

<table>
<thead>
<tr>
<th>Year 3</th>
<th>Materials preparation and implementation</th>
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</thead>
<tbody>
<tr>
<td>Jul. 18, 2012–</td>
<td>Study 2. VDPAM 419x, Advanced Swine Production Informatics Course (Fall 2012): The instructor embedded</td>
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<tr>
<td>Dec. 14, 2012</td>
<td>the swine scenario into two 1-hour intervention sessions in the elective VDPAM 419x course for second-</td>
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<tr>
<td></td>
<td>and third-year students at ISU. Pre-/posttests were given before/after intervention. The pretest was</td>
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<td></td>
<td>given at the beginning of the first class on Tuesday Sept. 11, 2012. Its scenarios included the swine</td>
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<td></td>
<td>and goat scenarios. The systems trainers applied the swine scenario to the first 1-hour intervention</td>
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<td></td>
<td>session on Sept. 18, 2012 and applied the systems model to the second 1-hour intervention session on</td>
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<tr>
<td></td>
<td>Sept. 25, 2012. The posttest was given at the end of the second intervention session on Sept. 25, 2012.</td>
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<tr>
<td></td>
<td>The same scenarios as in the pretest were given. Four 30-minute interviews with four students were</td>
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<tr>
<td></td>
<td>conducted after the posttest. TSM 327, Animal Production Systems Course (Fall 2012): Two 1-hour</td>
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<td></td>
<td>intervention lecture sessions were offered using the swine scenario for undergraduate students in the</td>
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<td></td>
<td>Department of Agricultural &amp; Biosystems Engineering at ISU. Pre-/posttests were given online before/after</td>
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<td></td>
<td>intervention sessions. The pretest, including both the swine scenario and the goat scenario, was given</td>
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<td></td>
<td>during the week of Sept. 3rd. The systems trainers applied the swine scenario to the first 1-hour</td>
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<tr>
<td></td>
<td>intervention session on Sept. 12, 2012, and applied the systems model to the second 1-hour intervention</td>
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<tr>
<td></td>
<td>session on Sept. 17, 2012. The online posttest was given for a week immediately following the second</td>
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<tr>
<td></td>
<td>intervention. The same scenarios as those in the pretest were given.</td>
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<tr>
<td></td>
<td>The HEC team members discussed and finalized the advanced swine scenario, the calf-management scenario,</td>
</tr>
<tr>
<td></td>
<td>and the beef-feedlot scenario with instructors at both ISU and KSU.</td>
</tr>
<tr>
<td>May 10, 2013</td>
<td>the goat scenario and swine scenario in the required VDPAM 445 course at ISU. Students were given</td>
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<tr>
<td></td>
<td>pre-/posttests before/after intervention. Six 60-minute individual students interviews and one 60-</td>
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<td></td>
<td>minute instructor interview were conducted after the posttest. Some third-year students who were taking</td>
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<td></td>
<td>VDPAM 310 at the time that had a 1-hour lecture by the systems trainer and a 30-minute quiz on</td>
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<tr>
<td></td>
<td>systems thinking. The instructor embedded the calf-management scenario and the beef-feedlot scenario</td>
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<tr>
<td></td>
<td>into two classes at KSU.</td>
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<tr>
<td>Sep. 11, 2013</td>
<td>HEC symposium at the Arkansas Association for Food Protection (AAFP, Sept. 10–11) meeting at the</td>
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<td></td>
<td>Chancellor Hotel in downtown Fayetteville, AR; final project report from each school for the funded</td>
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<tr>
<td>Aug. 31, 2014</td>
<td>HEC project ends.</td>
</tr>
</tbody>
</table>

Note. Activities in bold were used for this dissertation study.
The instructional changes made for this study included developing realistic scenarios for which practicing veterinarians might be called upon to analyze and suggest changes as well as incorporating and embedding scenarios in courses in the Veterinary Medicine curriculum. As part of the instructional changes, instructors provided students with the necessary background and descriptions of systems-thinking concepts. Additionally, the goal of instructional innovation required students to include systems thinking in analyzing scenarios and to discuss the importance and value of the accompanying scenario questions in reaching a systems-approach solution to the problem described in the scenario.

The scenarios were developed through a multistep process. The funded project’s first step was to bring a systems-approach expert, Chris Soderquist, to ISU for a 2-day interactive training exercise with participating faculty from ISU, KSU, and the University of Arkansas (U of Ark). Following this training, the food-animal course instructors worked closely with systems trainers and curriculum and instructional designers from these three schools to redesign their curricula and redevelop course materials. The instructors were from ISU and KSU; the systems trainers were from ISU, KSU, and the U of Ark; and the curriculum and instructional designers were from ISU. During the first two years of the project, four scenarios were created by ISU, KSU, and U of Ark faculty members. The scenarios were labeled: swine, goat, beef, and chemical hazard; cow; the format of these scenarios are summarized below and presented in their entirety in Appendices A through D. Each instructional scenario consisted of a theme; a scenario description accompanied by a situation; background information including time, location, the people or groups involved, and what problems were indicated; and a list of diagnostic questions for veterinarians (Veterinary Medicine students) to select in analyzing the problem scenario. As indicated
above, some of the diagnostic questions were consistent with a systems approach and others were consistent with a traditional, non-systems approach.

Research question 1 (Do systems-approach interventions lead to changes in students’ systems thinking?) was investigated by way of a basic pretest–posttest design. Three experiments, labeled Design Experiment 1, Design Experiment 2, and Design Experiment 3 were conducted in three classes at ISU during the Spring 2012, Fall 2012, and Spring 2013 semesters, respectively. The general pretest–posttest approach was used in each design experiment, but the methodology was adapted to fit the specific requirements of each experiment. Changes observed between the pretest to posttest were assessed to explain students’ knowledge gain. Each design experiment involved the introduction of the systems approach to a particular class. Students were asked to select a required number of the best diagnostic questions with which to analyze the scenario both before and after the instructional materials were presented. The specific design and materials varied within this basic structure to meet the specific requirements of each class. The three experiments were conducted in successive semesters. Consistent with the design research tradition, lessons learned during the application of the systems approach in prior semesters were applied to applications in subsequent semesters.

To address Research Question 2, in each class, students’ Veterinary Medicine admission data (e.g., undergraduate GPA) were examined for possible relationships with pretest/posttest performance. Analysis of variance (ANOVA; or analysis of covariance [(ANCOVA), depending on whether the entrance data were useful as covariates] was to be used across all parts of the study described in this dissertation. The specific research design of each experiment is described below.
Instructional Innovation in the Design Experiments

In the first few meetings of the Higher Education Challenge (HEC) project group during the fall of 2010, the systems trainers discussed possible ways to teach systems thinking to Veterinary Medicine students and methods that could be used for assessing student understanding. The researcher suggested that the faculty team members might create certain situations or real-life Veterinary Medicine cases that would allow students to act as if they were practicing veterinarians dealing with these situations or scenarios. Each scenario would be accompanied by a list of diagnostic questions. These questions would include both systems-thinking questions and non-systems-thinking questions. Students would be asked to identify a specific number of those questions that would be important in solving or dealing with the problem or issue given in the scenario.

As part of the design research, as the study progressed some changes were made between Design Experiment 1 and Design Experiment 2 and between Design Experiment 2 and Design Experiment 3 to improve the quality of the experiment. In Design Experiment 1, the course instructor developed the swine scenario with the systems trainers, prepared systems-thinking slides and scenario models, and utilized these systems-thinking materials in two lectures. Students in Design Experiment 1 were exposed to only a single scenario, one regarding swine, during the three pre-/posttests. The interval between the pretest and the first posttest was 3 weeks, and the interval between the first and second posttest was 50 minutes.

For Design Experiment 2, the systems trainers, along with one of the project faculty team members, developed the goat scenario, prepared systems-thinking slides and scenario models, and gave two lectures using these systems-thinking materials. The course instructor included no systems-thinking preparation or teaching for Design Experiment 2 due to a late
start on forming a new “advanced” swine scenario specifically for this class. The systems models were created, but the scenario wasn’t fully developed before the intervention semester began. Students in Design Experiment 2 received two scenarios, one each related to swine and goat, during the pre- and posttest period. The reason that the goat scenario was added to the experiment was to determine whether students could apply knowledge learned in the swine scenario intervention to the goat scenario, for which they received no intervention. In addition, the format of the pre- and post- assessments was changed in the second goat sub-problem scenario. In that scenario, the answer of each question on the list of questions was provided. Students were able to see the answers before they responded identified the best questions to ask. The systems trainer made these changes and hoped that this change would help students to focus on selecting the questions would better determine the problems in the overall system.

For Design Experiment 3, the two course instructors utilized the previously created swine and goat scenarios and scenario models, developed the systems-thinking slides, and taught these systems-thinking materials through three lectures. Students in Design Experiment 3 received four scenarios related to swine, goat, beef, and chemical hazard during the pre-/posttest period. The beef and chemical hazard scenarios were added to determine whether students could apply knowledge gained in this class related to swine and goat scenarios to the beef and chemical hazard scenarios. The reason for reverting to giving one pretest and two posttests was that, in Design Experiment 3, the interval between the pretest and the first posttest was 5 weeks, whereas the interval between the first posttest and the second posttest in Design Experiment 2 was only 2 weeks.
In the pre- and posttests, two diagnostic questions were modified. The first change was in the swine scenario. The ANOVA for Design Experiment 1 indicated that the result obtained for diagnostic question 18 (“What is the average parity of the farms?”) was not reliable. Therefore, after Design Experiment 2, the question was changed to “What is the average parity of the sows?” The second change was in the goat scenario. Most problems in the four scenarios asked students to select five diagnostic questions, whereas one scenario problem, in the goat scenario, asked students to select four diagnostic questions; thus, some students were understandably confused and had difficulty in completing the tests as requested. The systems trainers therefore added another systems diagnostic question “On average, how long do the animals spend in each type of pen (e.g., freshen, dry, milking)?” to the goat scenario. On the other hand, one format was changed in the pre- and posttests from the previous scenarios. Similar to the second goat sub-problem, the answers of each question on the list of questions in the beef scenario were provided. Students were able to see the answers before they responded which selections were the best questions to ask. The systems trainer made the changes and hoped students would instead of thinking whether the answers of each question on the list make sense of being the best questions, but focusing on which questions could better determine the problems in the system or big picture. In addition, the answers of 6 questions on the list were given differently between pre-posttests to prevent students from memorizing the systems diagnostic questions instead of understanding reasons for choosing them.

Confidentiality

All procedures for collecting, recording, and maintaining the confidentiality of student data were approved by the Institutional Review Board at ISU. Data from regular
course activities, such as tests and admission data, were provided to the researcher with a coded ID for the participants. Participants completed informed consent forms for participation in follow-up interviews (see Appendix P). In accordance with human subjects’ confidentiality requirements, for all three design experiments, each participant was given a participant code for the survey and the interview. The departmental secretary provided entrance scores identified only by participant code to the researcher.

**Assessment of Students Systems Thinking**

The general instructional approach described above was applied to three courses in the Veterinary Medicine curriculum at ISU. Four problem scenarios (see Appendices A–D) related to animal health issues were generated by Veterinary Medicine faculty at ISU, KSU, and the U of Ark. The impact of these scenarios, as well as the systems-approach intervention lectures, on the students’ learning of systems thinking was assessed by the number of systems-thinking diagnostic questions they selected.

A basic pretest–posttest design was used to assess changes in students’ systems thinking across each class. Various software options for developing the online tests in this study were explored. These applications included Google Forms (from Google Drive, formerly Google Docs), Qualtrics, and Thinkspace. Thinkspace was adopted to create the online beef scenario test at KSU because it allowed instructors to tailor their innovative instructional material using a platform that provided interactive feedback to student responses. After students submitted their answers, feedback information was grouped under their selected diagnostic questions. After multiple discussions, the development of the online test was customized. The food-animal course instructors collaborated with the instructional designers on the design, structure, and content of the online interactive test. Some limitations
were found while exploring online test options. First, Google Forms did not allow the
addition of graphics to the diagnostic questions, nor can it limit students to select a requested
number of diagnostic questions. Second, Qualtrics could not provide more than one student
feedback item for each diagnostic question. Finally, Thinkspace’s features were still under
development and therefore somewhat unsettled. In addition, the assessment formats varied
for different scenarios. Google Forms was utilized for the first pretest and Qualtrics was
used for the remainder of the tests at ISU.

The next chapter describes the specific instructional innovations applied to the three
Veterinary Medicine classes and the specific empirical research conducted to assess the
effectiveness of each innovation.
CHAPTER IV. EMPIRICAL SUPPORT

This chapter presents details of the three design experiments used to collect empirical data about the effectiveness of using a systems approach innovation in Veterinary Medicine classes. The three experiments were conducted during successive semesters. As described in chapter III, consistent with the general approach of design research, the results of earlier studies were used to inform the design of the innovations evaluated in subsequent experiments. The three experiments that comprised the study are referred to as Design Experiments 1, 2, and 3; this chapter presents the specific methodology, results, and discussion of the results for each of the three design experiments.

**Design Experiment 1: VDPAM 445, Spring 2012 (Class of 2013)**

Design Experiment 1 assessed the effectiveness of the first systems-approach intervention implemented in the VDPAM 445 – Large Animal Clinical Medicine course offered at ISU during the Spring 2012 semester. The systems approach is a problem-solving approach utilizing systems-thinking skills. Systems thinking is a problem-solving technique based on viewing systems as a whole rather than solving a single problem (Senge, 1990). The design experiment sought to answer the first research question, “Do systems-approach interventions lead to changes in students’ systems thinking?” It was hypothesized that students would demonstrate a higher level of systems thinking subsequent to instruction than they did prior to instruction.

**Method**

**Experimental design.** Design Experiment 1 used a pretest–posttest–posttest ANOVA design to determine whether performance improved from the pretest to the posttests. To improve statistical power and control any possible covariates that may have been correlated with the dependent variable, the use of an ANCOVA design was explored. Possible
covariates were collected (undergraduate GPAs based on total credits, cumulative, science credits, and the most recent 45 credits; cumulative, verbal, quantitative, and analytical writing GRE scores; qualifying exam scores; GPAs before and after pretest and posttests; VDPAM 445 grades for both the final exam and the course; time spent on the pre- and posttests; extra interventions from other courses; gender; ethnicity; and student city and state origin. Correlations between the pre- and posttest scores and all possible covariates were calculated. However, these possible covariates did not correlate with pre- or posttest performance, so the ANCOVA design was not used.

Students in Design Experiment 1 VDPAM 445 course completed a pretest assessing their systems-thinking abilities, received instruction on systems thinking, completed the first posttest late in the course, received additional instruction related to systems thinking, and then completed a second posttest after receiving that instruction. The experimental design sought to answer the following specific research questions related to the research question 1:

Research question 1a: Did students display more systems thinking on posttest 1 than on the pretest?

Research question 1b: Did students display more systems thinking on posttest 2 than on the pretest?

Research question 1c: Did students score higher on posttest 2 than on posttest 1?

Participants. The participants for this study were 155 third-year Veterinary Medicine students (49 males and 106 females) enrolled in a required course, VDPAM 445—Large Animal Clinical Medicine, at ISU for the Spring 2012 semester. All students were members of the Class of 2013. Students voluntarily filling out any of the three web-based tests received two extra credit points for each. Data from students were included in this study
only if they completed the initial pretest as well as both the first and second posttests. Of the 141 students who participated in the experiment, data from 112 (38 male and 74 female) students were deemed suitable for use in the analyses. Data were eliminated for 29 students who did not complete all three tests. Of these 29 students, 14 did not take the pretest, 11 did not take posttest 1, 10 did not take posttest 2, and six took only one of these three tests.

**Instructional innovation.** The instructional innovation features, including assessments, a Stella Systems diagram simulation model, and two intervention lectures, were designed by a team of course instructors, systems trainers, and instructional designers. The purpose of the instructional innovation was to get students to understand systems-thinking and to utilize it correctly in veterinary practice. The innovation was integrated into an existing course, VDPAM 445 – Large Animal Clinical Medicine, a 3-credit semester course with third-year classification in the College of Veterinary Medicine required for admission. The course covers the “clinical diagnosis and treatment of diseases of swine, beef, dairy, and small ruminant” (Iowa State University, 2012, p. 654). Three 50-minute sessions per week were held during the 16-week long semester course.

The instructional innovation was implemented during a 4-week segment of VDPAM 445 that focused on diseases and clinical treatment of swine. The innovation included one swine scenario and potentially relevant diagnostic questions a veterinarian might ask, PowerPoint slides, and Stella systems diagram simulation models corresponding to the swine scenario.

**Case scenario.** The case scenario in Design Experiment 1 involved swine (see Appendix A). The instructor in VDPAM 445, who specialized in swine health and was a HEC project team member, developed a draft swine scenario and a list of diagnostic
questions from an existing scouring piglets case. The scenario described the occurrence of an unacceptably high number of scouring piglets during farrowing in a farrow-to-wean sow operation and asked students what questions they should pose to determine how to improve the grow–finish performance as well as to improve the overall health of the herd.

Concurrently, the system trainers used the Stella application to create a systems diagram simulation model for this swine scenario. Also created were 20 diagnostic questions a veterinarian might ask when analyzing a scenario in order to identify the potential causes of the problem. For example, one of the 20 diagnostic questions in the swine scenario asked “What is the pH of the scours?” These questions established the direction of problem solving for this situation. Five of the questions created reflected systems thinking, and the remaining 15 questions did not reflect systems thinking. The diagnostic questions that reflected systems thinking considered the “big picture” that would help a veterinarian to effectively solve a given problem in a swine-raising system.

**PowerPoint slides and Stella systems diagram simulation models for intervention.** These systems-approach case materials were incorporated into the content of two 50-minute class sessions during the 4-week swine segment of the VDPAM 445 course, which were modified to include the systems-thinking intervention materials. The swine scenario was presented in first 50-minute class session of the 4-week course segment devoted to swine. This PowerPoint presentation provided swine background knowledge and systems-thinking concepts (see specifically Appendix E, slides 18, 19, 20, and also slides 10, 11, 16, 21, 23–27, and 54). In the PowerPoint slides, the instructor included a systems-thinking concepts discussion of differences between successful and unsuccessful client–veterinarian relationships. Successful relationships manage problem solving, create opportunity, and
successfully maintain all components simultaneously, whereas unsuccessful ones focus only on problem solving. Individuals who apply systems thinking consider the big picture instead of just the problem itself. The instructor explained how systems thinking could be used for both problem solving and communication. He then introduced five production inputs, i.e., nutrition, environment, disease, genetics, and management, into the piglet diarrhea swine Stella systems diagram simulation model. Basic flows in the model using these five production inputs were shown and discussed.

The second 50-minute modified lecture was given at the end of the 4-week swine segment of the course. At the beginning of this class, students were given 10 minutes to complete the first posttest. Operation of the swine Stella systems diagram simulation model (Figure 4.1) with some example simulations was then demonstrated. Some diagnostic questions arising in this swine scenario corresponding to the Stella systems diagram simulation model were explained without showing any systems-thinking Power Point slides. However, the instructor used the Stella systems diagram simulation model to illustrate systems-thinking concepts related to the systems diagnostic questions. For example, one of the systems diagnostic questions concerned the average weaning weight of the pigs. Instead of directly asking students the systems diagnostic question, the instructor explained that a manager should provide feedback to the owners. Further, the manager should be able to see the big picture of what is going to happen in the system, such as the fact that pigs will have slightly lower weaning in weight reflecting a quality difference between, for instance, market A and market B pigs. After the 30-minute lecture, students were given 10 minutes to complete the second posttest. A Stella systems diagram simulation model was created to
Figure 4.1 Swine Stella systems diagram simulation model.
complete the second posttest. A Stella systems diagram simulation model was created to clearly demonstrate how different results could be caused by changes in various factors. To present a system, a Stella model includes the following components: stocks (things that accumulate or conditions within a system; i.e., water in a cloud), flows (activities that cause conditions to change; i.e., evaporating or precipitating; Richmond, 1992), and the conveyor (the vehicle for capturing the delay, sometimes called the encountered reality). Flows include inflow (i.e., warm air rising or evaporating) and outflow (i.e., rain dropping or precipitating), as illustrated in Figure 4.2.

![Figure 4.2 Stocks and flows (Source: Richmond, 1992).](image)

**Assessment instruments**

**Pretest and posttests.** The design of the online pre- and posttests was customized after multiple discussions among the instructor, the instructional designer, and the systems trainers. All the instruments for Design Experiment 1 were finalized by early spring, 2012. The scenario, diagnostic questions, and order of questions were identical for all three tests
(pretest, posttest 1, and posttest 2). The researcher created the three tests online and sent them to the instructor a week before the class session.

The web-based pre- and posttests consisted of the swine scenario that presented certain swine health issues, a main problem question for the scenario, and 20 possible diagnostic questions for responding to the main question. The main problem question asked students to select, from the set of 20 diagnostic questions, the five best diagnostic questions they would ask the farm manager to determine the source of the piglet scouring problem. On each of the three pre-/posttests students were expected to select their perceived best diagnostic questions, but were not to answer the five they selected. The number of systems questions students selected was assumed to reflect the degree to which they were using systems thinking. The description of the scenario’s questions also indicated that there were no right or wrong diagnostic questions.

The diagnostic questions included five questions that reflected systems thinking and 15 that did not. The systems-thinking diagnostic questions used a systems-thinking approach, whereas the non-systems-thinking items used the traditional way of asking questions (see Appendix A. The systems-thinking approach considered direct and indirect factors when asking questions. For example, one of the diagnostic questions “How many pigs are scouring?” was a considered a systems question in that it requested information about the overall state of the health of piglets in the farrowing house. Depending on the answer to this question, the system could then be evaluated for issues/problems. The percentage of piglets affected with scours, as it is a biological process, would vary over time. Knowing the current percentage of piglets involved would help identify not only if, in fact, there was a current problem or not, but also the extent of the problem. As an output, once a
new intervention was implemented, one could then evaluate the impact of such intervention by monitoring the change in percentage of piglets affected after each intervention. On the other hand, the traditional approach did not consider the fundamental problems underlying the problem. For example, “What is the pH of the scours?” was considered a non-systems question” as it did not provide any information that could be used to evaluate the management or operational practices of the farm that might be contributing to the scouring problem. This question could be helpful in identifying the possible cause of the diarrhea (i.e., viral versus bacterial) and it could be helpful in implementing a treatment plan, but it does not address the core question regarding the effect of the overall sow and piglet flow as a possible major contributor to the system’s problem. Answers to this question could help a veterinarian put a “band aid” over the problem rather than focus on the root cause of the issue.

During multiple discussions about creating the assessment, involving course instructors, instructional designers, and system trainers, three online assessment applications were tested to determine the best fit for the instructors’ requests. The researcher first created the pretest on the Google Forms website for students to complete. Because Google Forms could not limit students to selecting only five questions, the final posttests were prepared using the Qualtrics software and website.

**Observation log.** The researcher observed and made written observation notes during the intervention and pre- and posttest sessions. These written logs consisted of the dates, starting times, ending times, and duration of the intervention and pre-/posttests; students’ reactions to the instruction during the interventions, the Stella systems diagram simulation model, and the pre-/posttests; a description of instructor activity during the class sessions; the
context, outline, and content of the lectures; the instruments used in the lectures such as PowerPoint, pre- and posttests, and Stella systems diagram simulation models; and how much extra credit was given to those completing the tests. Some notes were generated from the Qualtrics website, which automatically recorded data when assessing students’ posttests. These notes included the average time students spent on the tests; special cases, such as students who selected more than the required five diagnostic questions in the pretest or submitted the same test more than once in the posttests; and the number, gender, and class year of the participant for each test.

Procedure. The instructional intervention took place during the 4-week swine segment of the VDPAM 445 course extending from April 2, 2012 to April 27, 2012 (Table 4.1). The intervention was conducted in two 50-minute sessions on two different days. During the first class day of the swine segment, the instructor posted the uniform resource locator (URL) of the pretest on the Blackboard course-management system (CMS) just before the start of class. After a 10-minute introduction to the swine segment of VDPAM 445, students were instructed to use their laptops\(^4\) to log on to the pretest, complete it within 10 minutes, and log off. The instructor next presented a 30-minute PowerPoint lecture that briefly and indirectly introduced systems-thinking ideas and techniques and applied them to swine issues. The systems-approach ideas described in the lecture included flows such as input, output, and communication in multiple systems (shown in the PowerPoint description; see Appendix E). The rest of the content and course materials were the same as those used for that course the previous year.

\(^4\)All students in Veterinary Medicine are required to purchase a specific type of laptop to bring to class.
Table 4.1  
Table 4.1

<table>
<thead>
<tr>
<th>Date</th>
<th>Time spent/activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr. 2 (Mon)</td>
<td>10-minutes: onsite pretest</td>
</tr>
<tr>
<td></td>
<td>30-minutes: systems-approach swine intervention 1</td>
</tr>
<tr>
<td>Apr. 27 (Fri)</td>
<td>10-minutes: onsite posttest 1</td>
</tr>
<tr>
<td></td>
<td>30-minutes: systems-approach swine intervention 2</td>
</tr>
<tr>
<td></td>
<td>10-minutes: onsite posttest 2</td>
</tr>
</tbody>
</table>

At the beginning of the last class session of the VDPAM 445 course, the instructor posted the URL for posttest 1 on Blackboard. Students were given 10 minutes to log on to the test website and complete the posttest. During the remainder of the class, the instructor presented the Stella systems diagram simulation model of the swine scenario and applied the systems approach analysis to the assessment scenario. The instructor showed how changing one factor affected another. In the last 10 minutes of the class session, the instructor posted the URL for posttest 2 on Blackboard and students were given 10 minutes to complete it.

Thus, for VDPAM 445, the new instructional intervention and assessments consisted of a pretest, a PowerPoint class lecture applying a systems approach to Veterinary Medicine, an initial posttest, an analysis of the swine scenario using the Stella systems diagram simulation model (Figure 4.1), and finally, the second posttest. The instructor used the scenario and diagnostic questions as part of the intervention and as a student-assessment vehicle.

Statistical analyses. Data were analyzed using the Statistical Package for the Social Sciences (SPSS) computer package. To answer the research question “Do systems-approach interventions lead to changes in students’ systems thinking?” the quantitative data from the pretest and posttests were analyzed using repeated measures ANOVA with the SPSS general
linear model (GLM) procedure. In addition, descriptive statistics such as frequencies, means, standard deviations, and percentages were computed.

Results

A one-way repeated measures ANOVA model was estimated to compare pretest, posttest 1, and posttest 2. Bonferroni-adjusted posthoc comparisons were used to compare the individual pairs of means. The ANOVA was significant, $F(1,111) = 22.59, p < .001, MSE = 277.66$, partial $\eta^2 = 0.169$. The descriptive statistics are presented in Table 4.2, and

Table 4.2

<table>
<thead>
<tr>
<th>Test</th>
<th>$M$</th>
<th>$SD$</th>
<th>SEM</th>
<th>95% CI</th>
<th>$N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest***</td>
<td>27.8</td>
<td>16.1</td>
<td>1.5</td>
<td>24.8–30.8</td>
<td>112</td>
</tr>
<tr>
<td>Posttest 1 ***</td>
<td>33.9</td>
<td>13.4</td>
<td>1.3</td>
<td>31.4–36.4</td>
<td>112</td>
</tr>
<tr>
<td>Posttest 2 ***</td>
<td>42.7</td>
<td>20.0</td>
<td>1.9</td>
<td>38.9–46.4</td>
<td>112</td>
</tr>
</tbody>
</table>

Note. Repeated measure ANOVA for pretest, posttest 1, and posttest 2 correct percentages, with Bonferroni adjustment (Bf), $p < 0.0167$.

Table 4.3

Summary of the Comparisons among the Pretest, Posttest2, and Posttest 2 Means with Bonferroni Adjustment

<table>
<thead>
<tr>
<th>Tests I, J compared</th>
<th>Mean difference (I – J)</th>
<th>SE</th>
<th>Sig.(^a)</th>
<th>Cohen’s $d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest 1 – Pretest</td>
<td>6.1*</td>
<td>1.5</td>
<td>&lt;.001</td>
<td>.41</td>
</tr>
<tr>
<td>Posttest 2 – Pretest</td>
<td>14.9*</td>
<td>2.6</td>
<td>&lt;.001</td>
<td>.82</td>
</tr>
<tr>
<td>Posttest 2 – Posttest 1</td>
<td>8.8*</td>
<td>2.4</td>
<td>.001</td>
<td>.52</td>
</tr>
</tbody>
</table>

Note. Based on estimated marginal means.

\(^a\)Adjustment for multiple comparisons: Bonferroni.

*Mean difference is significant at the .05 level.
the comparisons of the cell means are presented in Table 4.3. The pretest differed from both posttest 1 and posttest 2, posttest 1 differed from posttest 2, and all comparisons were significant. Performance increased across all three tests. Using the square root of the mean square error as the estimate of the within-cell standard deviation, the Cohen’s $d$ statistic for each of the differences was calculated, as reported in Table 4.3. Although the overall level of performance on the final posttest was moderate at best (43%), using Cohen’s rough values of less than .3 indicating a small effect, .3–.8 a moderate effect, and above .8 a strong effect, the Cohen’s $d$ results suggest that the effects from pretest to posttests were in the moderate to strong range.

**Discussion**

The initial assessment of this first introduction of systems thinking in a Vet Met class demonstrated that students more frequently selected systems-based actions following instruction than before instruction. Students selected more systems-approach diagnostic questions on the posttests than on the pretest. Although the differences were not large, students evolved from about one quarter of their selections being the systems-based alternatives (similar to what they may have chosen by chance given that five of 20 alternatives were systems choices) to about 40% of their selections being systems-based approaches by the end of the class. Overall, the effect of testing time accounted for a moderate 17% of the variance in assessment scores. Using the square root of the mean square error as an estimate of within-session variance, the Cohen’s $d$ measure of effect size was .41 between the pretest and posttest 1, .82 between the pretest and posttest 2, and .52

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5In using these verbal descriptors, it is important to understand that they are relative to the domain of research. These rough ranges are typically used in the educational research domain, particularly for relatively short-term interventions.
between posttest 1 and posttest 2. These effect sizes are in the moderate to strong range as defined by Cohen (1988). These results supported the proposition that the instructional intervention led to modest increases in the students’ use of system thinking in dealing with swine health issues that a veterinarian might face. This positive result is moderated by several limitations in the study.

**Limitations.** The researcher recognizes that this initial incorporation of the systems approach content into veterinary instruction at ISU represents a minimal innovation. During the 4-week segment of the class, students received only two 50-minute lectures that discussed the systems-approach. Embedded within these two lectures were discussions about the alternative diagnostic questions used in the specific scenario presented in the assessment. Given this relatively low level of instructional intervention, the results were considered promising and informed the development of the remainder of the project. The reasons for this limited exposure included the need to develop the new instructional approach within a relatively tight time frame, the complexity of integrating new ideas across an already-densely packed course syllabus, and the time needed for busy instructors to process new ideas and fully integrate them into the curriculum.

Additional limitations included the tight time frame between the instructional delivery and the assessment and the use of the same test items for the pretest and both posttests. With respect to the tight time frame between instruction and assessment, even though the first use of the assessment items on the pretest represented items unfamiliar to the students, the students did receive instruction on the same swine scenario during the initial lesson. Twenty-five days later, the students took the same posttest and then received instruction on the same swine scenario that referred to the appropriateness, from a systems-approach perspective, of
the 20 items on the pretest and posttest. Immediately after that instruction, students received the same assessment for the third time. Given that they had just received instruction on those specific items, it is not surprising that their performance improved. The research design could not rule out the alternative hypothesis that the improved performance could be due to students’ rote memorizing of correct responses in contrast to actually developing an understanding of the systems-approach concepts. The goal in teaching the systems approach is to have veterinarians use systems-approach concepts in new health situations in their future practice. That is, the goal is long-term transfer of understood concepts and principles of the systems approach. A limitation of the present experiment is that the results do not provide clear evidence of transfer of understanding to new situations. Although it could be argued that the research on “worked examples” (Atkinson, Derry, Renkl, & Wortham, 2000; Clark, Nguyen & Sweller, 2006; Sweller & Cooper, 1985) used early in the learning process justified the instructor directly discussing the scenario used in the assessment, to provide clear evidence of the efficacy of the instruction, knowledge gained from worked examples needs to be assessed in transfer situations. Assessing transfer to new examples has been part of much of the previous research on worked examples.

A further limitation is that students, given limited instruction, could have been cognitively overloaded with new knowledge on systems dynamic modeling with simulation while simultaneously learning a new concept. Using more scenarios during instruction might help students to distinguish between systems and non-systems questions and to incorporate systems thinking more effectively into their knowledge structures about production animal medicine. To create additional scenarios, instructors might use the “train the trainer”
approach to guide students to create their own scenarios, ask questions, and in particular, to ask systems questions.

**General implication for future research on the systems approach.** As noted above, the results provide some moderate evidence that students’ understanding of systems thinking improved over the time of the instruction. These results were sufficiently encouraging to support subsequent iterations and scaling up of the systems-approach instruction in other classes. A second experiment, described next, addressed some of the limitations of the first experiment. That subsequent experiment incorporated an additional scenario on goat alopecia, the assessment of the transfer of systems thinking to new problems or issues, and the ability of students to produce systems-thinking alternatives to case scenarios. In addition, one systems diagnostic question in the swine scenario was modified due to inconsistency.

In addition, qualitative research should examine students’ reactions to the interventions and case scenarios. For example, each group of students should be interviewed individually in a subsequent iteration of systems-thinking instruction in the same course as well as in different courses. Interviewing a group of students and instructors across iterations would produce greater in-depth knowledge of students’ understanding of systems thinking. Consistent with the design research principle, that knowledge could guide the ongoing modification and redesign of systems-approach instruction. The systems-approach intervention should be incorporated throughout a course to enable students to easily utilize systems thinking. Ultimately, for maximum impact, systems thinking should be infused throughout all courses as well as throughout the Veterinary Medicine program itself.
Design Experiment 2 assessed the effectiveness of the second system approach intervention implemented at ISU during the Fall 2012 semester in VDPAM 419x – Advanced Swine Production Informatics.

**Method**

**Experimental design.** Design Experiment 2 involved systems-approach intervention incorporated into a small class of five students. The findings were based on qualitative interviews with the five students, collected after the class was completed. Students also completed a pretest and a posttest during the class. Because of the small sample, and as expected, the quantitative analysis showed the differences between the pre- and posttests were not statistically significant. The means and standard deviations are presented in the data analysis section below.

**Participants.** There were five ISU Veterinary Medicine students (one second-year and four third-year students; three males and two females) enrolled in the elective VDPAM 419x – Advanced Swine Production Informatics course. All five students voluntarily filled out the two web-based tests and participated in the individual interviews after the last class session without receiving extra credit points or any other compensation.

**Instructional innovation.** The instructional innovation, including the assessments, the Stella systems diagram simulation models, and an intervention lecture were designed by the same team of course instructors, systems trainers, and instructional designers that developed the instructional materials for Design Experiment 1. For Design Experiment 2, two case-based scenarios were created for the students’ assessment. Two Stella systems diagram simulation models were created and demonstrated during the intervention. Rather than having the course instructor present the systems-thinking instruction in the existing
course, the systems trainer and a systems graduate student were invited to be guest lecturers for two class sessions, and they presented the innovative systems-thinking components for the VDPAM 419x course.

**Instructional setting.** VDPAM 419x is a 1-credit semester course entitled Advanced Swine Production Informatics. This elective course is open to second- and third-year students in Veterinary Medicine. The course covers (a) the concepts and tools involved in collection, manipulation, analysis, and reporting of production, financial, diagnostic, and clinical data used by swine production companies; (b) evaluation of the validity of the collected information; and (c) the types of information tools that can/should be used after making practical and useful recommendations.

The innovative instructional materials, which included two scenarios (swine and goat) and the associated diagnostic questions, were created by two other faculty members in Veterinary Medicine. PowerPoint slides were created by the system trainer, and the Stella systems diagram simulation models corresponding to the swine and goat scenarios were created for the course intervention by the systems graduate assistant. The assessment materials included pre- and posttests, student interviews, and an observation log created by the researcher for assessment. Each instrument is explained below.

**Case scenarios.** About two months before the start of the course, the course instructor began communicating with the system trainer about developing an advanced swine Stella systems diagram simulation model based on an existing swine case. The original plan was to use the swine Stella systems diagram simulation model to develop a new advanced swine scenario and a list of diagnostic questions to embed within the course. However, there was not enough time to develop them before the course started. Therefore, instead of
creating a new scenario, the researcher suggested that the systems trainer give lectures using
the swine and goat scenarios (see Appendices A and B) previously created by two other
faculty members at Veterinary Medicine. The instructor agreed to have two lectures
introducing systems thinking be taught by the system trainers while he was away at a
conference. These lectures were based upon the swine and the goat Stella systems diagram
simulation models developed previously. These two 50-minute systems-thinking
intervention lectures were prepared as PowerPoint presentations and taught by the systems
trainer and the systems graduate assistant. For the first lecture, the system trainer used
PowerPoint slides (see Appendix F) that had been created at the beginning of the HEC
project to train the team members in systems thinking. Because the research plan allowed
students to complete the pretest a week before the systems innovation class, the entire 50-
minute class time was devoted to the systems-thinking lecture. The PowerPoint presentation
introduced the eight systems-thinking concepts and provided veterinary medicine examples
representing each concept. For the second lecture, the systems graduate assistant
demonstrated the previously created swine Stella systems diagram simulation model and
discussed the model and its content with the students. The goat Stella systems diagram
simulation model (Figure 4.3) was also briefly discussed because students were interested in
that topic.

During the summer of 2012, the VDPAM 445 instructor, a ruminant specialist,
developed a draft of the goat scenario from an existing alopecia case and prepared a list of
diagnostic questions. There were two subproblems comprising the goat scenario. The first
goat sub-problem scenario described a herd of milking goats that had had a history of
alopecia during the winter months over the past 7 years and asked students what questions
Figure 4.3 Goat Stella systems diagram simulation model.
they should ask to begin to gain an understanding of the issue. The second goat sub-problem scenario described additional information obtained from the owners and asked students to select the most important questions that would lead to solution to the problem.

Students were asked to analyze the scenario and select the four most important diagnostic questions from a list of 16 possible questions for the first sub-problem and to select the five most important diagnostic questions from a list of 14 possible questions for the second subproblem. The systems graduate assistant concurrently created a goat Stella systems diagram simulation model (Figure 4.3), which was a system model that included inputs, outputs, conditions, reality situations, and global changes over time as variables. From the model simulation, students were able to see the possible reasons underlying the goat alopecia problem and to prioritize the diagnostic questions a veterinarian or manager should ask.

**Assessment instruments**

*Pretest and posttest.* The pretest and posttest assessments were similar to the those used for Design Experiment 1. Each assessment consisted of two scenarios involving a health issue and a list of possible diagnostic questions a veterinarian might want to have answered to deal with that health issue. The researcher created the pretest and posttest and placed them, including the previously created swine and goat scenarios, on the Qualtrics website. The scenarios and questions for the pretest were same as for the posttest. There were two parts to the assessment: one involving goat and one involving swine. The numbers of diagnostic questions were different for the two scenarios.

For the swine scenario assessment, students were asked to analyze the scenario problem and select the five most important diagnostic questions that a veterinarian should
initially ask in order to understand the situation. From the 20 possible diagnostic questions, the students were told to select the five that best represented systems thinking. There were two subproblems for the goat scenario assessment. Students were asked to analyze the scenario and select the four most important diagnostic questions out of 16 for the first subproblem and the five most important diagnostic questions out of 14 for the second subproblem (see Appendix B).

Students were directed to select a specific number of diagnostic questions as the best diagnostic questions for each scenario but to not answer the questions they selected. The selected diagnostic questions were to represent the total number of systems-oriented diagnostic questions in the specific scenario. The number of systems questions students selected was assumed to reflect their degree of use of systems thinking and was the score they received on the test.

Interview guide. The individual student interviews were designed to elicit insight into the cognitive impact of the students’ experiences as well as to obtain their reactions to the new instructional approach. These data were collected for formative assessment to inform future curriculum and instructional development. A student interview guide (Table 4.4) was created prior to the course intervention. The students were asked what they had learned about systems thinking from the systems-approach lectures, how they would interpret systems thinking to a friend, and what changes they would make with respect to systems-thinking teaching and assessment. The interviewer asked students to articulate their thinking and to provide open-ended feedback without distraction or influence from other students. By conducting individual interviews, the researcher was better able to understand each student’s thinking and reasoning processes. Students could explain more details of their understanding
of systems thinking. The goal of the interview session was to provide the researcher with greater in-depth vision and understanding of students’ reactions and interpretations of the systems approach. Furthermore, student feedback in the interviews provided narrative and

Table 4.4

*Interview Guide for Students in Design Experiment 2*

1. What is your experiences and reaction to
   a. the new instructional approaches (systems approach)
   b. formative assessment (scenario and diagnostic question items)

2. What have you learned about systems thinking (ST) from the 2 guest lectures?

3. What would you tell a friend about the ST (interpret the ST, feeling about utilizing the ST, easy or difficult to understand what the instructor was saying)?
   a. What are the things you liked most about learning using systems thinking?
   b. What are the things you liked least about learning using systems thinking?
   c. Would you recommend participation in systems thinking to colleagues at other institutions? Why?

4. Compare the systems approach and traditional teaching when learning similar content; which one is easier and why? Would you select a course using systems thinking over a course that did not?

5. What would you change about systems thinking teaching if you were the instructor?
   a. What materials would be helpful for students learning the concept of systems approach?
   b. What practices could help students to better demonstrate systems approach in the class?

6. What are your suggestions for creating scenarios with system diagnostic question items as well as assessing students’ understanding of ST?

7. Do you think about diagnosis differently now that you have done the ST training? Give an example of your thinking (student’s thinking and reasoning processes in-depth).

8. Please provide any suggestions that you have for the individuals who are directing the systems thinking learning.

9. How else might you want to interact with the guest lecturers?

10. If you could have another systems approach classes what would you want to learn about other than the subject matter?

11. Do you plan a career in food-animal health management?
contextual information for this study. An iTalk application for the iPod was used to record the interview conversations. The researcher also took notes while interviewing the students.

**Observation log.** The researcher observed the classes during the intervention and pretest and posttest class sessions. The researcher used two video cameras on tripods to record the interaction between the system trainers and students in the class. The front camera was used to record students’ reactions, and the rear camera was used to record what students were doing during the lectures. In addition, the researcher used the iTalk application on an iPod to record the in-class discussion. The Camtasia application was used to record the presentation on the trainer’s computer screen. The researcher made written notes in observation logs during these class sessions. After each class, the researcher transcribed the recorded videos and audios.

In the logs, the researcher recorded the following information in two parts—pre- and posttests and intervention lectures—as follows:

A. Pretests and posttests

1. Description of the participants for each test: the number of students (five), gender (three males and two females), and class year of the participants (one second-year and four third-year students).

2. Dates (pretest: Sept. 11; posttest: Sept. 25), starting and ending times (pretest: 7:00–7:10 a.m., at the beginning of the class; posttest: 7:40–7:50 a.m., at the end of the class), and duration (10 minutes).

3. Location: Pre- and posttests were both taken in the classroom.

4. Students’ reactions to, interactions with, questions about, and problems regarding the pre- and posttests: one student had trouble submitting the tests
because he did not closely read the instruction that he could not submit the test without selecting the required number of questions. The researcher helped this student and found he selected five instead of the required four questions in the first goat scenario. The student was able to submit the test after correcting the selection number.

5. How many extra credit points given upon test completion: none.

6. Researcher’s reflection of the pre- and posttests: Most of the case scenarios’ problems asked students to select five diagnostic questions except the one goat scenario sub-problem that asked for four to be selected. It might be helpful to ask students to select five diagnostic questions consistently across all scenarios’ problems. This situation should be fixed for the next experiment.

B. Intervention lectures

1. Description of the participants (the numbers, genders, and class year of the participants for each lecture were same).

2. Dates (first lecture: Sept. 18; second lecture: Sept. 25), starting and ending times (first lecture: 7:00–7:50 a.m.; second lecture: 7:00–7:40 a.m.), and duration (first lecture: 50 minutes; second lecture: 40 minutes).

3. A description of what the systems trainer and graduate assistant who delivered the interventions did in the class sessions (first lecture: the systems trainer provided the lecture; the content did not directly connect to the Advanced Swine Production Informatics course; and the outline, content, and PowerPoint slides utilized were the same used when the instructors were trained on systems thinking; second lecture: the systems graduate assistant
demonstrated the simulations of the swine and goat Stella systems diagram simulation models).

4. Students’ reactions to, interactions with, questions about, and problems regarding the instruction during the interventions and Stella systems diagram simulation models (first lecture: there was not much interaction during the PowerPoint lecture; second lecture: students answered and asked questions during the simulations of swine and goat Stella systems diagram simulation models).

**Procedure.** Design Experiment 2 was conducted in the VDPAM 419x course during two 50-minute sessions of two different class sessions; in addition, part of one additional class session was used for giving the pretest (see Table 4.5). The researcher prepared the pre- and posttests, including the swine and goat scenarios, on the Qualtrics website for use in the student assessments. Students were requested to fill out two web-based tests. The scenarios and questions in the pretest were the same as those in the posttest.

The pretest was given at the beginning of the class one week before the first intervention class session. Students were given 10 minutes to complete the pretest. The first intervention class session was 50 minutes long. The second intervention class session one

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<th>Date</th>
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<td>Sept. 11 (Tue)</td>
<td>10-minute onsite pretest</td>
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<tr>
<td>Sept. 18 (Tue)</td>
<td>50-minute systems approach swine intervention 1</td>
</tr>
<tr>
<td>Sept. 25 (Tue)</td>
<td>35-minute systems approach swine intervention 2 and 10-minute onsite posttest</td>
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week later was 35 minutes long. Students were given 10 minutes at the end of the class session after receiving the second intervention lecture to complete the posttest.

During the first intervention class session, the systems trainer introduced systems thinking using the PowerPoint presentation (see Appendix F). One week later, the systems graduate assistant presented the Stella systems diagram simulation model based on the swine scenario during the first 35 minutes of the second intervention class session. In the first intervention lecture, the systems trainer introduced the purpose of this HEC project and the important need for food safety. By showing swine- and vet-med-related examples and real cases, the concept of systems thinking and the eight skills that can help veterinarians make better decisions while problem solving were illustrated. In the second intervention lecture, the systems graduate assistant presented a 5-minute PowerPoint description of a hog scour scenario and what variables should be included for problem-solving. He then demonstrated a swine Stella systems diagram simulation model for 25 minutes and a goat Stella systems diagram simulation model for 5 minutes as illustrations of systems-thinking concepts related to systems diagnostic questions. For example, one of the systems diagnostic questions concerned the average time goats spent in each type of pen (e.g., freshen, dry, milking). Instead of directly telling students the systems diagnostic questions, the systems graduate assistant explained that, when the manager found out the owners had misdiagnosed the goats’ pregnancy, these misdiagnosed goats stayed in the dry pen, where they should not have been. Because the goats received no pregnancy detection, they just lingered for 60 days, until the owners discovered they had not given birth. The owners had to have these goats rebred and wait another 150 days. That flawed approach caused the goats stay in the dry pen for a very
long time. After model simulations, the posttest was given during the last 10 minutes of the second intervention session.

The researcher scheduled interviews with each student via e-mail after the second intervention class session. The interviews were 30 minutes in length and were audio-recorded. The interview sessions were conducted individually, at five different times, and at locations in the Veterinary Medicine complex. In each session, instructions were given to the participants to ensure that the steps of the process were clear. Questions were read to each participant. For purposes of anonymity, each student was assigned an alphabetical code: Students A and C were female students; and students B, D, and E were male students.

After qualitative data collection, audio files were transcribed and entered into a Microsoft Word file on the researcher’s personal laptop computer. The transcript data were organized by participant and question. Students’ responses were reviewed multiple times to identify the emerging themes: understanding, transferring, and improvement.

Statistical analysis. Because there were only five students taking the VDPAM 419x course, there was insufficient statistical power to provide evidence of reliable change between the pre- and posttest. Based on the results of Design Experiment 1, students were expected to show some performance improvement between the pretest and the posttest. The descriptive data show the means of pre- and posttests for the five students (Table 4.6). For

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<th>Mean percent correct</th>
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<tr>
<td>Pretest</td>
<td>37</td>
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<td>Posttest</td>
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completeness, the means, standard deviations, and standard errors on the pretest and posttest are presented in Appendix G.

**Qualitative analysis.** The results section focuses on the qualitative content analysis of the observational data and the interviews. The purpose of the content analysis in Design Experiment 2 was to determine whether students apply systems thinking to their problem solving and decision making. Specifically, it was intended to discover whether students improved their performance on problem solving after intervention. In addition, long-term transfer of understood concepts and underlying principles of the systems approach to new situations was investigated. The analyses included interpreting themes and texts from the observation logs compiled during the intervention lectures, the pre- and posttest results, and the interviews; interpreting students and instructors reactions from the video recordings of the intervention lectures and pre- and posttests; interpreting transcriptions from the audio recordings during the interviews; and the researcher’s reflection.

The qualitative data from the interviews were organized using the NVivo 10 computer program and qualitative analysis strategies, e.g., coding and categorization. After data collection, an identification number for each participant was created. The data were then prepared for analysis by transcribing the audio-recorded interviews and then entering the text into word processing (Microsoft Word) and spreadsheet (Microsoft Excel) programs.

The process of analyzing the qualitative data was accomplished according to methodology described by Taylor-Powell and Renner (2003), as follows:

1. Write down impressions while reading the text from the observation log, watching the video from the intervention, and listening to the audio from the interviews.
2. Organize the interview data to identify consistencies and differences by looking at how individuals responded to each question.

3. Categorize, subcategorize, label, and code the data to identify the patterns, starting with the preset categories approach and then adding other categories using the emergent categories approach. Create labels for each category and subcategory and then code the labels in preparation for the frequency count.

4. Summarize each category and identify the connections and correlations for each.

5. Finally, interpret the key points and important findings from the connections, and address the limitations and possible alternative explanations for the data collected.

**Results**

The results are divided into three major sections: (a) the degree of students’ understanding of systems thinking, (b) students’ capability to transfer knowledge into a new field, and (c) students’ concerns with respect to learning and teaching systems thinking. Findings about students’ interpretation of systems thinking, suggestions for teaching, and assessments to improve students’ systems thinking were naturally related to the degree of students’ understanding of systems thinking. The findings regarding students’ capability for giving examples on applying systems thinking learned in one field to another were focused on their transferring capabilities. A set of questions on learning and teaching systems thinking were related to students concerns. This section of the analysis includes a summary description with illustrative quotes from the individual interview data and an interpretation.

**Understanding of systems thinking.** In this first area of qualitative findings, understanding was examined through the responses to six items: (a) tell a friend about systems thinking, (b) modify the teaching if you were the instructor, (c) suggestions for creating scenarios with system diagnostic question items as well as assessment, (d)
increasing interactive learning on systems thinking, (e) thinking about diagnosis differently, and (f) comparing the systems approach to traditional teaching. The degree of student understanding of systems thinking was characterized by the following experiences shared by students during the individual interview sessions.

All five participants claimed the idea of systems thinking was not new to them because it was either taught in other swine courses or used in previous pig production jobs:

We as swine/food-animal students already are taught by a systems approach so I don’t feel that the system is that new. (student A)

As swine focus, we’ve kind of got a little better understanding maybe of systems thinking. . . . Swine and poultry courses . . . teach some systems thinking . . . they just don’t know that’s what they’re teaching. (student B)

Being a large-animal student . . . [the Veterinary Medicine faculty] kind of teach us to think like that already . . . hey never kind of put a term to it. So they’re always talking about their relationships and how to look at things; how they fit together. . . . That was helpful in kind of putting an image or a name to the way that they were kind of already teaching us. (student C)

A swine veterinarian realizes every point of entry that a disease might have, and they’ll account for. . . . They look at everything that goes in and out of a system. . . . The concept’s pretty well understood already. . . . I think we use systems thinking quite a bit without calling it systems thinking. (student D)

That’s what we’re taught in the Vet Med curriculum . . . take what you learn in one species and, where it’s possible, apply it to the next, you know. Not everything’s the same but some general concepts are going to be alike. So in a herd situation you
would know certain physiological things like . . . the dry goats kept in a room with no lighting . . . about the pathology of Vitamin D, hypo Vitamin B . . . You just take those things and reapply them . . . We’ve already learned. . . . I work in pig production and that’s a lot of system thinking already, so I guess that’s why the idea wasn’t really that new to me. (student E)

Most students thought their diagnosis decisions were based on their previous knowledge and were no different after the two systems-approach intervention lectures:

I don’t really think about diagnosis differently because we have used this approach in other swine courses (student A)

[Systems thinking intervention] probably just made me more aware that that’s what I was doing when I work my way through a problem. . . . I always just take a step back and make sure that you’re still using that type of thinking. (student B)

It’s really similar to how I thought before, but now that I know there is something called the systems approach . . . I think I’m better capable of thinking like that. (student C)

I didn’t use systems thinking [for diagnosis] per se. (student D)

[My decision for the diagnostic questions depends on] somewhat past knowledge. . . . I know what I would do in that situation. I know what other veterinarians have done . . . what would benefit . . . do a CVC on a gilt. . . . That’s not going to tell you much about the population; it’s going to tell you what’s going on with her, not [with] the rest of them. . . . No [I did not learn from the two intervention lectures] . . . it’s more based on previous knowledge. (student E)
On the other hand, student C believed his systems thinking ability was enhanced after the two intervention lectures:

Before the lectures, I think I used a little bit of the systems approach—because we’ve kind of taught that. . . . as well as a little bit of just my own background. . . . The second time I definitely thought of it more as like think of the whole picture—how does everything connect to each other. I was thinking more about the seasonality of things because that was brought up in maybe one of the scenarios, I don’t remember. But I think I thought about it differently the second time. (student C)

However, students’ interpretations of systems thinking as they related it to a friend were limited when asked for the definition and the concept. The students included both pros and cons as well as some components of the eight systems-thinking techniques, such as seeing the big picture, crossing disciplinary boundaries, input and output, and interconnection, as illustrated in the following passages:

Looking at the overall picture but also individual animals . . . it offers a consistent method to evaluate situations. . . . It is somewhat easier once you develop those thinking skills. (student A)

The ability to step back . . . picture the diagram . . . instead of letting everything get cluttered in your head . . . the inputs and outputs and how that goes into the system. . . . If you use the systems type approach, I think it would probably . . . make things easier, because I think it really makes you think about what’s going on and what’s changing. You know, what’s going into a system, what’s coming out of it, and . . . help you in the end know where to focus . . . not really thinking about as an animal for a second. . . . [Once you figured out where problems might be in the system . . .}
you can start applying your medical analogy . . . first . . . asking all the clinical signs . . . then . . . look at . . . a flow chart . . . As far as with diseases, I guess it’s all about the population as a whole. And that’s probably why I guess you’d have to kind of adapt the style. Because if you’re talking about a system as, you know, an entire barn or a pig flow, or if you’re talking about a system as the animals, the system, so I think there’s a lot of ways to apply it. (student B)

[It’s] an interesting way to kind of look at things to prioritize your thinking. . . . It’s important to take all of the variables into account . . . thinking that you have to zoom out and see the whole picture and try to understand how everything is interconnected and what the relationships are between every piece of the puzzle. And then when you’re . . . trying to figure out what’s wrong with the veterinary thing, you need to see which part is affected, and how the other parts are interacting with that. So you have to understand how everything works together in order to figure out what’s wrong. . . . So instead of just brute memorizing everything . . . understanding the context and what the results are if you tweak this, then this happens then you would kind of know what the disease process is and then how you can treat it . . . It helps you see things you wouldn’t have seen before and that maybe you can solve problems. I guess you get to questions that you probably wouldn’t have asked before if you weren’t thinking about the whole system and how everything is connected. (student C)

[Systems thinking is] kind of an engineering approach to the medicine, looking at flow or progression of things and everything that goes in and out of the system, and realizing every little part of that. (student D)

Thinking about things on the system level as opposed to an individual animal level or
an individual person level . . . decisions are made based on what we see on an overall basis not just what we see from an individual standpoint. . . . You do see that as an individual animal, but you make decisions based on all the animals versus just that individual animal. . . . It’s easy to make change because you base [it] on data. You have concrete facts. Things move more quickly using system thinking. You can make faster decisions, I feel, using data-driven decisions that way. . . . It’s important for veterinarians to learn this type of thinking. . . . It would be a good continuing education class. . . . The systems approach I think helps identify and prioritize risk factors. (student E)

When the Stella simulation model was introduced to apply systems thinking, student C was reluctant to develop his own model from scratch: ”I like using models that are already made, not necessarily making my own.”

The reasons those students were not able to fully understand systems thinking might be due to the short duration of intervention; confusing PowerPoint lectures; the Veterinary Medicine curriculum that only teaches individual animal approaches; and the feeling that they were there to pass the Veterinary Medicine board, not learn systems thinking, and they could figure systems thinking out by themselves:

I didn’t really see what we were supposed to learn in the two lectures that would change our answers on the assessments. . . . The first lecture was sort of long and confusing, and I didn’t really get much out of it. . . . It takes a while to develop a systems-thinking mind set. (student A)

It was a little overwhelming to see all the factors that go into it, but I mean, I guess that kind of teaches you a lesson, too. It’s not as simple as we think of it sometimes,
either. . . . What a lot of people wouldn’t like about it is that they’ve kind of got a stigma attached to a veterinarian that you’re just a wealth of medical knowledge and you can just figure it out. . . . [For] swine class, two or three [intervention lectures] is plenty. [For] Vet school as a whole, need some more. . . . But time is valuable. . . . I think with cattle they still focus on the individual. It’s individual medicine. And the swine and poultry, it’s all about population medicine. And now they’re starting to go back more to individualized care. (student B)

To me [the Stella systems model demonstration] didn’t have a ton of merit. I guess I didn’t really know what to use. I didn’t know what to walk away from kind of plugging numbers into the equation. I can understand better maybe how that’s used in other engineering situations, but that part didn’t have a lot of value to me. (student D)

To be able to think on a system-wide level is going to take extra training. . . . After only one lecture it’s hard to really grasp the whole concept that [the lecturer] was trying to get across. No, I don’t feel I understand it completely . . . but I think I agree with his thinking behind it . . . because that’s where livestock production, food production, is going. . . . It’s hard to explain to the public that sees an individual animal . . . because all people see is individual animals, they don’t see herd. And explaining how you make decisions based on a population sounds impersonal. (student E)

Most everything in the Veterinary Medicine curriculum is [an] individual animal [approach]. . . . We don’t learn system thinking in Vet Med; we learn individual animal thinking. So, no it’s not taught right now. . . . It’s hard to make those
[decisions to cure individual animals or set to kill]. This is why we euthanize; this is why we send these animals to market even though they’re perfectly healthy. (student E)

We’re here to pass veterinary boards, and that’s not something currently on veterinary boards, so is it important? Yes. Is it necessary for us to complete our education? Probably not . . . I don’t think that [applying a Stella model to learn systems thinking] was the reason [or purpose] why I took the class. I took the class to learn production records and how they’re used on the farm, and not necessarily how a system works.

[The Stella model and production records and how they’re used on the farm is] a separate topic . . . interesting topic, but it’s not applicable, I don’t think it’s something that should be taught in swine production records. Our goal is to analyze records and make production decisions and not to learn a systems-based thinking (student E)

Most of the students would have preferred to have step-by-step training that would go through each scenario and the diagnostic questions to confirm their selections:

I would have loved to go over the assessment to see what the most appropriate answers should have been. . . . We should have [gone] over the assessment at the end to see if we really understood the concept or not . . . examples of real life situations and working through them. (student A)

A lot of us in the swine industry already think that way to a point. We just don’t, we haven’t really looked at how we’re approaching the problem. . . . You really just got to work through problems until you start to get it. (student B)

It would have been helpful, even if we did guess what [the systems diagnostic question] was, just to work through [the case] step by step. (student C)
It’s more important to explain to people why we do and how it’s done as opposed to trying to get them to think that way. . . . Discuss why you picked, you chose what you did or didn’t; that’s where the value comes into those things—making you first think about it. But if all you do is think about it and answer something, you don’t necessarily know whether that was right or wrong. It might not be necessarily right or wrong, but you need to know other peoples’ reasons for why it would be right or wrong. (student E)

As the students reflected, in order to allow them to understand systems thinking thoroughly, it would have been helpful to include more real-life examples and work through them with a number of exercises, playing with multiple cases in Stella simulation models interactively, asking students both backwards and then in the normal way to determine the gaps reflecting what they missed when solving a problem, and giving an assignment to work through a problem both before and after intervention, but not necessarily have more intervention:

[Having] more interactive with . . . the computer model would be helpful in practice . . . versus listening to a lecture. . . . Allowing more demonstrations or real-life examples of the systems learning thinking . . . go over real life examples.(student A)

Make sure we were all on the same page as what was going on. . . . It would be helpful to have people make the flow diagrams . . . not as complicated . . . give them the scenario, and say make a flow diagram. And then, you know, list every input and output you can think of. . . . Most people will forget, you know, all the different factors, I mean there’s hundreds, so I think showing them that, here’s what they had . . . this simple little diagram, and then showing [the] lecturer’s diagram . . . there’s
factors playing into this way more than you’re probably thinking about unless you’re using systems thinking looking for those factors that could change an outcome. . . . Two [lectures] is enough for a group, but I think really you’ve got to have, like, take-home problems. . . . Work through a problem and then teach, and then do your two lectures and work through a problem again . . . multiple choice . . . maybe little more open and just kind of limited steered you a little bit towards the things you wanted to find out. . . . Case studies, that type of thing, would be helpful in a situation before and after getting those two lectures. . . . [It’s] probably more helpful to just talk it out . . . or write it out instead of just a multiple choice type thing. I guess that’s a lot harder to grade or check or whatever. But yeah, the same question but just, what do you do? . . . [First of all, we have open-ended questions; the second question will be the selections from the list. And then if some of the questions weren’t on your list, you can add in]. . . . It’s definitely more applicable to figuring out if people are learning . . . what systems is really about. . . . [The] multiple choice thing didn’t . . . correlate with what we learned there. . . . [The] professor had to explain how a pig flow works. . . . [Especially] the small-animal folks really struggled in the repro section because they were still thinking, you know, non-systems . . . the small-animal people . . . [it] might take them a little longer to kind of figure out what’s the whole thinking approach. I guess you might need to proceed slowly. (student B) [For] complicated case-based learning . . . I would teach students the system and then after they understood the system, then like say, this is a problem in this area, and then have them try to learn how to use that type of thinking. . . . More cases [can help the student learn the concept of system approach]. . . . It would have been helpful to go
through a bunch of cases to really show how important it is to understand the system for solving some cases . . . probably could have covered four [instead of two cases during the intervention . . . spent a lot of time discussing it]. . . . [A] student could do a project on laying out a system and then having a case within that and then having to present it to other students . . . [in] a small group. . . . If it’s a class of like 150, you could split them into groups of five and have everyone do a quick 5-minute presentation about their system and a case within it or something . . . ask [students] questions about the system and see if they really understand how the system works, then ask if this part of the system was disrupted, what would be the consequences . . . backwards from the way we were thinking about it. . . . [so] they understand the importance of the system and the consequences of changes. . . . [Assessment methods] depends on the type of information you want. . . . Teach [the students] about swine production and that whole system. . . . Say . . . you have a swine outbreak, and as a result you’re going to have 40 of your 100 sows are going to abort late term: “What are going to be the consequences within that system because of those signs?” And then students would have to say, you’d have smaller litters, you’d have lower numbers of pigs that you’re weaning, you’d have lower income, you’d have more returns, you’d have a lot more breedings to do the next week. So . . . that way you know they kind of understand the system. . . . [Students need to have previous knowledge in order to support the questions you ask] . . . what are some things that could cause a decreased number of pigs at weaning: decreased size in pigs at weaning and increase in returns. And so then they’d have to think backwards, like what in the system would affect those things. (student C)
The lecture can probably be condensed. . . . [The Stella simulation] model was interesting when [you] kind of start plugging numbers into different things and kind of [see] how that would affect a system. . . . Go through the flow and diagram, you know inputs and outputs, and just, I guess, making people cognizant of the true flow of pigs through a system. Or just the potential vectors of disease. I think is pretty interesting when you take that holistic approach. . . . A worksheet or something maybe more interactive, that would kind of challenge the students to apply that kind of systemic approach. . . . Have a day [when the lecturer] comes in . . . [and] keeps the lecture broad with diagrams and kind of making people think systemically or with the systems approach. And I would follow that up with kind of a worksheet or some sort of activity to make it more interactive. . . . [The model] might be helpful for some people just to look at a system approach [to] bring a more holistic view of biosecurity and disease process to them, but I don’t think there needs to be more. I would either keep it the same or trim it down a little. . . . I could create a model . . . just identifying inputs and outputs; that’s really where the value would be to me. . . . Computers [would be helpful for the students learning the concept of systems approach] . . . case studies [practice could help the students to better demonstrate systems approach in the class] . . . to test their thinking. . . . A fun exercise. . . . I wouldn’t just pose a problem or pose some sort of a disease event or health event and then have every student map a system approach model with. . . . I would have a case and have students draw a model . . . have situations like [an] outbreak, give every student a sheet of paper that said you have a PRRS outbreak. Draw a concept map . . . put it up on Elmo, and compare and contrast and see what we learn from each other. . . . Have everybody just
unguided by a word bank or anything . . . draw it out . . . [then after you draw, maybe you have a hundred items of diagnosed what you should do the next, or what you should ask for, the situation, in order to pursue further actions. And then afterwards, five of you discuss each single one and say, this one is system thinking or not, or this one is most important or not]. To a level that would apply to us; I think that [two lectures of intervention], that’s enough. (student D)

[What Dr. H] presented was kind of a compressed version of probably something that he spent a lot more time on. . . . It would [warrant] more time than he spent on it. . . . The presented model can be changed to an interactive; give people the model and let them play with it. You’d learn more that way. . . . [Everybody plays with the] model and then . . . ask questions. . . . Have a scenario printed out: . . . go in the model and change this, this, and this. What is it . . . what happens? What’s your interpretation of why did these numbers change? That kind of thing, so just let people play with the model. It would give them a better understanding of [systems thinking]. . . . I would not necessarily encourage them to participate; I would just encourage them to understand it because that’s the problem that we face in the animal industry is that people have lost that sense of why we make the decisions we do because they don’t think on a system level. (student E)

To increase interaction in the class, some students suggested playing a scenario game or using devices such as clickers or online applications such as RW (ResponseWare) poll:

You could use clicker questions via RW poll or ask questions of individuals in the class. (student A)

People who’ve never experienced [a hog farm outbreak, playing swine scenario
games in the class] that’s a really [good] way of teaching that (student C)

Have students draw on whiteboard, unguided [to interact with the guest lecturers].

(student D)

Some students believed systems thinking would benefit differently focused students in some way:

Might be even better . . . giving it to more small-animal focused people . . . more benefit out of it just from giving it to a group that doesn’t have anything to do with systems thinking. . . . Pretty much anybody else . . . swine and poultry, are . . . [already taught] some systems thinking. . . . Small animal, they’re all patient-focused and it’s very, I guess, medically minded instead of systems. . . . [VDPAM445 Clinical Medicine] is definitely a place [to teach systems thinking] . . . because everybody’s taking it . . . [especially for] the large-animal focus then, yeah, that would be the ideal place. . . . I don’t know exactly how that would apply to the beef and small ruminant side of things but . . . [it’s] obviously directly applicable to the swine portion. So I think it would help people get through the swine portion better to know, to understand that systems (student B)

It might have more application than the other parts of veterinary medicine, like the horses, small-animal med; I don’t think they maybe apply kind of the systemic approach to medicine quite as much. . . . I would recommend people to systems thinking that struggle to see big picture inputs and outputs of a system. (student D)

I’m a context person, so it’s important for me to understand the context when I’m learning something. Because if there’s no context then I feel like there’s no point in learning it. . . . So I think the systems approach, there’s always context to what you’re
talking about. So you can always figure out how that fits into the system, and how it affects the system. So I think that makes it maybe more relevant and maybe easier to learn because it’s relevant. (student E)

**Transferring systems thinking.** In the second area of the qualitative finds, a key item that was posed related to transferring and the example of telling a friend, along with experiences and reactions to the formative assessment of the goat scenario.

Although student D was not sure how to approach a problem using systems thinking, he thought asking the right question should be based on learned knowledge and previous experience, commenting: “[I’m] not sure how to apply [systems thinking]. . . . I guess to ask the right questions, you’re kind of looking at your most likely things based off experience and based off what you’ve learned.” In addition, student B thought it necessary to know all the terminology before working through the problems, stating: ”There’s no way you can, you know, work your way through the problems later if you don’t understand all the terminology.

However, most students were able to provide examples and describe how to apply systems thinking in different situations on a regular basis. The students’ comments included the following:

 Basically, for a breeding herd, as far as how you get from a sow being bred to how many sows or pigs weaned per year, all the different factors that go into . . . those steps . . . [that the] herd is hitting, and seeing how that affects the next step in line . . . [you say], “Here’s the points where it’s hitting, here’s where it’s input, how does it change the output?” (student B)

Someone who’s small animal . . . hasn’t really learned about population medicine as much . . . [so it] might be more difficult for them to understand. . . . But . . . it ties in
with physiology being a system, and so you could do it on an individual animal basis as well. . . . You need to understand your clients as a veterinarian: how they raise their animals and what their system is because there might be something you didn’t even think to ask about that might be making a huge difference. . . . [It’s] important to ask the producer . . . “Walk me through the life of one of your goats. . . . What would happen to that goat over a year period? . . . That might help you get a better idea of production. . . . In small-animal internal medicine . . . you can think of physiology like a system. . . . If you understand the system, then you can understand what’s wrong . . . [and] understand what you have to do to treat it. (student C)

Biosecurity is a lot of times really just breaking down kind of that same philosophy. . . . Maybe the systems approach is a pretty good way to explain biosecurity . . . because that’s a good way to identify all the risk factors coming into a farm and moving disease out of a farm. (student D)

To determine what sows to cull . . . you can’t look at one sow’s litter today. She had a small litter and [you] decide she’s going to be culled. That’s the way we used to do it, but if you look at the trend over time and also the trend within the herd, to cull her or not . . . if you say, “I’m going to cull every sow that doesn’t produce more than nine pigs per litter, on average,” and if you cull her, well, [and] don’t look at the entire system, you could have the entire herd dropping below nine pigs [per] litter and you’d be culling the entire herd. So picking on an individual animal basis is not going to get you anywhere. You have to think on the whole scale. (student E)

**Concerns of learning and teaching systems thinking.** In the third area of the qualitative results, students’ concerns about learning systems thinking were discussed by
posing one question: What is your experiences and reaction to the new instructional approaches?

Despite the good assessment design, student E was concerned about the safety of the systems training: “Those [diagnostic scenarios] . . . can get dangerous, using those test questions, because in a clinical situation you might not do what is on there.” On the other hand, student E believed that more opportunities for practicing systems-thinking techniques would be more helpful than adding extra lectures, saying:

I think that [using half an hour to explain the model] was enough to explain it. It’s pretty easy to understand once you see it. But I think you would gain a better understanding of it when you use it. So I think getting it explained more wouldn’t be any use; actually using it would be useful.

Discussion

Design Experiment 2 was planned to assess students’ qualitative reactions to the redesigned systems approach instruction in order to inform future development of the instructional innovations. Although students’ ability to apply systems approaches to new veterinary problems was assessed using an objective test, the small number of students made it very unlikely that statistical differences would be found. The major instructional changes from Design Experiment 1 to Design Experiment 2 were to increase the amount of instruction students received by including a 50-minute lecture and a 35-minute simulation in systems-approach instruction. An additional change was to assess students on multiple topics. Students completed an assessment on swine about which they had received direct instruction; students also completed an assessment on a goat scenario, which evaluated their ability to transfer systems thinking to new topics.
From the quantitative analysis, students’ understanding of systems thinking improved modestly (i.e., about one half of a standard deviation). Students did better at selecting systems-based questions on the posttest than they did on the pretest. Although the small number of participants means there was insufficient statistical power to meaningfully assess differences statistically and that the Cohen’s $d$ value could not be overly trusted or interpreted, the pattern of change was consistent with the change in Design Experiment 1. That latter consistency provides some, albeit limited, evidence that performance improved.

From the individual interviews, all five participants claimed the idea of systems thinking was not new to them because it was taught in other swine courses in Veterinary Medicine. Therefore, most students’ diagnostic decisions for the scenarios were based on their previous knowledge and were not influenced by the intervention lectures. Following the intervention, students were able to provide examples, describe how to apply systems thinking, and provide suggestions on efficient learning and teaching of systems thinking concepts. However, students’ interpretation of systems thinking was limited to the pros and cons, the big picture, cross-disciplinary boundaries, input and output, and interconnection. One student was not able to transfer and apply his understanding of systems thinking to new situations. He thought asking the right question should be based on learned knowledge and previous experience. Another student also thought it was necessary to know all the terminology before working through the problems.

According to the students’ responses, some students were not able to fully understand that systems-thinking confusion might be due to the short duration of the intervention; the confusing PowerPoint lecture; personal stigma; the Veterinary Medicine curriculum individual-animal teaching approach; and that students were focused on passing the
Veterinary Medicine board, not learning systems thinking. Although the assessment was designed to determine whether students’ systems thinking ability improved due to the intervention content without providing the correct answers, most students preferred step-by-step training that goes through each scenario and diagnostic questions to confirm their selections. Students seemed to need to know the correct answers to determine what kinds of questions were systems questions and why.

To obtain a better result with respect to learning systems thinking, students suggested the following methods. First, more real-life examples should be included so they can work through with a number of exercises and interactively play with multiple cases using Stella simulation models. Second, students should be asked questions backwards and then the normal way for them to see gaps in learning they missed when solving a problem. Third, interaction in the class should be increased by using devices such as clickers or online applications such as the RW poll. Fourth, rather than having more intervention, assignments to work through a problem should be given before and after intervention. Students suggested that increasing opportunities for practicing systems-thinking techniques would be more helpful than adding extra lecturers.

**Limitations.** Although the Design Experiment 2 provided richer information regarding student perceptions of teaching and learning of systems thinking, it also shared three of the primary limitations of the first study. First, the intervention was limited to only two class sessions, and second, the design did not allow for measuring whether learning gains transferred to contexts other than the swine and goat scenarios involved in the instruction. Third, students, given the limited instruction, could have been cognitively too overloaded with new knowledge on dynamic systems modeling with simulation to learn a new concept.
Given the short duration of the intervention, students were not able to understand the concepts explained in the PowerPoint lecture. Most students preferred step-by-step lessons that would have gone through each scenario and diagnostic questions to confirm their selections, although the assessment was designed to determine whether students’ systems thinking ability improved due to the intervention content without providing the correct answers. Students’ needed to know the correct answers to reason what kind of questions are systems questions and why. On the other hand, the existing Veterinary Medicine curriculum taught only the individual animal approach, and students were focused mainly on passing the Veterinary Medicine board exam.

**General implication for future research on the systems approach.** The results of this experiment demonstrated that students’ understanding of systems thinking improved slightly. Students’ performance increased about 6% from pretest to posttest. However, according to the interviews, most students already had perceptions of the production industry prior to intervention. They were able to provide examples of systems thinking and suggestions for efficient learning and teaching. A third experiment, described below, addressed some of the limitations of the present one. That subsequent research incorporated a larger number of scenarios across a broader range of food production and processing safety and health issues, the assessment of the transfer of systems thinking to new problems or issues, and the ability for students to produce systems-thinking alternatives to case scenarios. In addition, one systems diagnostic question was added to the goat scenario due to the confusion regarding the total number of questions for students to select. A few answers on the posttest were modified in the beef scenario to prevent students memorizing the responses.
Some questions were added in the student interview guide to better determine students’ thoughts regarding systems thinking.

On the other hand, qualitative research should also include an examination of instructors’ reactions to the interventions and case scenarios. Interviewing the instructors across several iterations would lead to greater in-depth knowledge of instructors’ suggestions. Consistent with the design research principle, that knowledge guided our ongoing modification and redesign of the systems approach instruction.

Interventions should be carried out multiple times in order for students to significantly utilize systems thinking. To improve students’ learning of systems thinking, instructors need to develop more real-life examples/scenarios and incorporate exercises that allow students to manipulate the Stella simulation models interactively. Activities with such scenarios/models should be designed to allow students to develop a schema for systems approach questions and help them develop a pattern of systems thinking. These activities should make clearer the difference between systems and non-systems questions and incorporate systems thinking into the knowledge structures they utilize for comprehension. To create additional scenarios, the instructors might use the “train the trainer” approach, guiding students to create their own scenarios, ask questions, and ask systems questions. In addition, the instructors can offer practice opportunities by giving assignments to work through a problem before and after an intervention and using a device, such as clickers, or an online application, such as an RW poll, to increase interaction in the class.

**Design Experiment 3: VDPAM 445, Spring 2013 (Class of 2014)**

Design Experiment 3 was intended to assess the effectiveness of the third implementation of the systems-approach intervention in the VDPAM 445 – Large Animal
Clinical Medicine course at ISU during the Spring 2013 semester. Based on the results of Design Experiments 1 and 2, modifications were made in the design of the instruction for Experiment 3. Two instructors in VDPAM 445 added more systems-thinking content to their PowerPoint lectures to provide students with more opportunities to learn about systems thinking. See Appendix H and I for the actual PowerPoint presentations for these lectures; the added slides are indicated. It was hoped that this increased instruction would help students improve their ability to utilize systems thinking while engaged in diagnostic problem solving. In previous versions of the assessment instruments (pretest and posttests), the number of diagnostic questions students were required to select varied from one section of the assessment to another. For example, the number of diagnostic questions to be selected varied between the goat and the swine scenarios. Some students found this variation confusing; therefore, the number of diagnostic questions students were asked to select was held constant in each section of the assessments for Design Experiment 3.

In addition, the assessments were planned to assess transfer as well as direct learning. This was accomplished by examining whether the improved ability to use systems thinking transferred from the topics taught in these courses to other topics. If the students showed improved performance on other topics, that finding would provide evidence of transfer to new topics. The students received direct instruction involving the goat1, goat 2, and swine instructional scenarios, but not on the chemical1, chemical2, and beef scenarios. Thus, improvements in performance from pretest to posttest for goat1, goat 2, and swine would represent direct learning, and any improvement on the other scenarios would represent some degree of transfer.
One of the systems-diagnostic questions in the swine scenario was modified because of its low reliability in Design Experiment 1. The question “What is the average parity of the farms?” was modified to “What is the average parity of the sows?” to increase the internal consistency of the assessment. Finally, based on the results of Design Experiment 1, it was hypothesized that students would demonstrate a higher level of systems thinking on posttests administered after instruction than they demonstrated on a pretest given prior to instruction. More specifically, it was expected that student performance would improve from pretest to posttest 1 to posttest 2 on both direct and transfer assessments.

Method

Experimental design. Design Experiment 3 used a pretest–posttest quantitative ANOVA design. Students in the class of 2014 enrolled in the Spring 2013 semester VDPAM 445 course completed a pretest assessing systems thinking, received instruction on systems thinking with respect to a goat topic 2 weeks later, completed the first posttest 4 weeks after the goat intervention, and received additional instruction on systems thinking with respect to a swine topic immediately after the first posttest. Two weeks later, during the last class session, the students receive additional instruction on systems thinking with respect to a swine topic. At the end of the same class, immediately after instruction on systems thinking, students completed the second posttest. Thus, the experimental design consisted of a pretest, two posttests, one instructional session on goat, and two instructional sessions on swine.

As in Design Experiment 1, the use of an ANCOVA design was explored for Design Experiment 3. Several possible covariates were collected (cumulative, science, and the last 45 credit undergraduate GPAs; cumulative, verbal, quantitative, and analytical writing GRE scores; Veterinary Medicine qualifying examination scores; Veterinary Medicine GPAs before pretest and after posttests; VDPAM 445 grades for both the final exam and the course;
time spent on the pre- and posttests; extra interventions from other courses; gender; ethnicity; and city and state of student residence). Correlations were calculated between the pre- and posttest scores and each of the possible covariates. However, none of the possible covariates correlated with pre- or posttest performance, so ANCOVA was not used. One possible reason for the low correlations may be the demanding selectivity of the Veterinary Medicine program. Such selectivity limits the variance with respect to these possible covariate variables, and range restriction limits the size of the possible correlations.

Finally, observational data and interviews were collected as described below and used in the qualitative analysis.

**Participants.** The participants for this class were 147 third-year ISU Veterinary Medicine students (41 males and 106 females; class of 2014) enrolled in a required course, VDPAM 445 – Large Animal Clinical Medicine for the Spring 2013 semester. Students who voluntarily filled out the web-based tests received five extra credit points in this class for completing the pretest and three extra credit points for completing each of the two posttests. Student data were included in this study only for those students who completed the initial pretest and both posttests. Of the 147 students who participated in the course, data from 109 (30 male and 79 female) were used in the analyses. Data were eliminated for 38 students because they either did not submit the first posttest before the second intervention, did not complete all three tests, or both. Of these 38 students, nine did not take the pretest; eight did not take posttest 1; 20 did not take posttest 2; three did not take at least two of the tests; six submitted posttest 1 late, after the 2nd intervention; and two were both absent and submitted posttest 1 late.
After the last class session, six 60-minute individual interviews, each with a different student, were conducted and audio-recorded. In addition, one 60-minute interview with one of the course instructors was conducted and audio-recorded immediately following the second posttest.

**Instructional innovation.** The same team of course instructors, systems trainers, and instructional designers as in Design Experiments 1 and 2 designed the instructional innovation, the Stella systems diagram simulation models and intervention lectures, and the assessments for Design Experiment 3. As noted in the introduction, a greater variety of case scenarios were created for student assessment and two Stella systems diagram simulation models were demonstrated to the students. Thus, additional systems-thinking instruction was embedded into the existing VDPAM 445 course. For example, the goat Stella systems diagram simulation model was demonstrated in the ruminant animals’ session and the swine Stella systems diagram simulation model was demonstrated in the swine session. Furthermore, in two swine lectures, the swine instructor applied and discussed systems-thinking concepts that related to current course materials.

VDPAM 445 is the same semester-long course used in Design Experiment 1, but Design Experiment 3 was conducted in the subsequent year. The first two-thirds of the course centered on diseases and clinical medicine for ruminant animals. The final third of the course was focused on diseases and clinical medicine for swine. The instructional innovation was implemented during two different segments of VDPAM 445: a 5-week segment that focused on diseases and clinical medicine for goat, swine, and cow and a 4-week segment that focused on diseases and clinical treatment of swine.
The systems-approach innovation used in Design Experiment 3 included two scenarios (goat and swine), PowerPoint slides, Stella systems diagram simulation models for intervention, and pre- and posttests. In addition, interviews conducted with students and instructors as well as observation logs were used as part of the assessment. Each of these components is explained below.

**Case scenarios.** Four 50-minute lectures from this course were modified and incorporated into the intervention sessions for this study. Among the four created scenarios, two scenarios were used for intervention in this class. The first scenario, conducted in the first third of the course, concerned goat. The second scenario, conducted in the final third of the course, concerned swine. The third and fourth scenarios were used only as part of the assessment and were not discussed during interventions.

**Goat scenario.** The first case scenario, similar to the one used in Design Experiment 2, focused on goats and was based on an existing alopecia case. The goat scenario was developed in the summer of 2012 by the ruminant instructor of VDPAM 445 using the same scenario as in Design Experiment 2. However, one system diagnostic question was added in this study to prevent confusion with respect to the number of questions required to be selected. The goat scenario consisted of two sub-problem scenarios, each having a list of diagnostic questions from which students were to select. The first sub-problem scenario described a herd of milking goats with a history of alopecia during the winter months in the past 7 years. Students were asked what questions they should ask to begin to understand the issue. There were 17 possible diagnostic questions from which students were to select five. The 17 diagnostic questions included five that reflected systems thinking and 12 that did not. The second sub-problem scenario described the additional information obtained from the
owners and again asked students to select the most important questions for solving the problem. There were 14 possible diagnostic questions from which students were to select five. The 14 diagnostic question alternatives included five that reflected systems thinking and nine that did not.

Swine scenario. The second case scenario involved swine and was based on an existing piglet scouring case. The scenario, similar to that used for Design Experiments 1 and 2, described a large number of scouring piglets in farrowing in a farrow-to-wean sow operation and asked students what questions they should ask to improve the grow–finish performance as well as to improve overall herd health. To improve reliability in this experiment, one diagnostic question was modified from the scenario used in the first two design experiments. The scenario included one problem and 20 possible diagnostic questions. Again, among these diagnostic questions five reflected systems thinking and fifteen did not. The students’ task on the pretest and posttests was to analyze the scenario and select, from the list of 20, the five best diagnostic questions they would ask the farm manager to determine why the farm was having the piglet scouring problems.

Chemical hazard scenario. The third case scenario was created in the summer and fall of 2012 by the systems trainer at ISU, two postdoctoral investigators in food science at the U of Ark, and USDA FSIS staff and involved a food-safety chemical hazard issue. The scenario included two sub-problem scenarios. The setting of the first sub-problem scenario occurred at a pork packing plant at which carcasses had overly high levels of antimicrobials residues. Although the live animal producers claimed that recommended withdrawal times had been followed for all antimicrobial treatments, a USDA veterinarian routinely retained carcasses from specific farms for chemical residue analysis and found levels that were too
high. The first sub-problem scenario had 12 possible diagnostic questions, of which five reflected systems thinking and seven did not. The second sub-problem scenario involved further information regarding the Public Health Veterinarian (PHV) source state or owner identity, information usually unknown to inspection personnel at the time carcasses or animals are selected for testing. Having producers sign a statement ensuring that stated withdrawal times have been observed for any drugs or chemicals administered or applied may not always be reliable in preventing violations related to such residues. The second sub-problem scenario had 11 possible diagnostic questions, including five diagnostic questions that reflected systems thinking and six that did not. Again, the students’ tasks on the pretest and posttests were to analyze the scenario and select from the list of 12 (first subproblem) or 11 (the second subproblem) diagnostic questions the five best that a veterinarian should initially ask in order to address this potential food-safety hazard.

**Beef scenario.** The fourth case scenario was a beef cow–calf scenario. This scenario was created in the fall of 2011 by three faculty members along with a HEC project team member beef specialist from KSU. The scenario included one presenting problem regarding crossbred cows and heifers. The owner had trouble maintaining his first calf heifers in the breeding herd, experiencing pregnancy percentages 8% lower than the target of 95% bred. There were 20 possible diagnostic questions from which students were to select 10. The diagnostic questions included 10 that reflected systems thinking and 10 that did not. Again, the students’ task on the pretest and posttests was to analyze the scenario and select from the list of 20 diagnostic questions the 10 best for identifying the major problem in this herd.

**PowerPoint slides and Stella systems diagram simulation models for the intervention.** Some of the contents of four 50-minute class sessions from the 16-week
VDPAM 445 course were modified to include the systems-thinking intervention materials. Two of the seven instructors who taught this course revised portions of their existing course materials and sequences to incorporate the systems approach into the goat and swine scenarios. The instructor who focused on diseases and clinical medicine for goat, swine, and cow did not have extra time to deliver systems-thinking materials in the first one-third course segment. Therefore, a 12-minute goat scenario and Stella systems diagram simulation model intervention for the first modified lecture were prepared and delivered at the beginning of class in the eighth week, during the second third of the course segment focusing on the gastrointestinal (GI) system.

In this intervention lecture, the instructor gave a 6-minute systems-thinking overview of systems-thinking concepts without PowerPoint slides. The instructor used an example of type II ketosis in dairy cattle on which he had lectured earlier in the class. He explained that, in contrast to a traditional Veterinary Medicine perspective focused on individual animals, the systems-thinking mindset is more effective in determining real problems in an agricultural operation by including consideration of overall environmental and management systems. The instructor also mentioned the goat scenario used in the pre- and posttests. Then, in the final 6 minutes, the systems graduate assistant demonstrated the goat Stella systems diagram simulation model. He showed the goat system diagram, gave students a cursory look at how this Stella systems diagram simulation model was constructed, and described how these animals flowed through the agricultural operation and key disease processes relevant to this particular case. He argued that the point of modeling on paper or using a computer is to operationalize one’s mental model and examine system features to confirm correctness. He further argued that, through the modeling process, one is able to
directly change one’s assumptions and instantly see outcomes due to changes of various parameters. After the intervention, the instructor who focused on the GI system proceeded to teach the regular course material without any systems-thinking involvement.

The other three modified lectures were held during the last third of the course. At the beginning of the second modified lecture, the instructor, who focused on diseases and clinical treatment of swine, gave a 10-minute introduction to this class. Students were then given 15 minutes to complete the first online posttest in the class. After the test, the instructor used PowerPoint slides to teach a 25-minute lesson incorporating systems thinking. The PowerPoint slides had been created by the instructor in the fall of 2011 and modified in the fall of 2012. These slides described relevant background information relative to swine and provided Veterinary Medicine examples of using systems thinking. These examples are described in Appendix H (slides 17-19, 10, 11, and 21–60). Similar to Design Experiment1, the instructor included systems-thinking concepts in the PowerPoint slides by discussing differences between successful and unsuccessful client–veterinarian relationships. The successful relationships manage problem solving, create opportunity, and successfully and simultaneously maintain all three components, whereas unsuccessful ones focus only on problem solving. Individuals who apply systems thinking consider the big picture. The instructor explained how systems thinking was used for problem solving and communication. Then, the instructor introduced a five production input fishbone diagram for piglet diarrhea that incorporated different elements from nutrition, environment, disease, genetics, and management. He explained that disease (i.e., sanitation) as well as quality control should be emphasized at the farm level for improving nutrition (e.g., agalactia), the environment (e.g., cold drafts), and genetics (e.g., receptors) and at the management (e.g., cross-fostering) level.
for people. Basic flows of the five production inputs in the swine Stella systems diagram simulation model were presented and discussed. For example, the instructor explained that the swine production system could be considered to have three distinct phases of production. Each of these phases has distinct requirements related to space, design, and labor. The basic flow diagram (Figure 4.4) explains how all these systems fit together in the general scheme. The basic flow starts with a sow unit where breeding animals are kept.

These sow units produce baby pigs weaned between the ages of 12 and 28 days (at 8–25 lbs.). Most operations wean with a target of age of 18–21 days (10–15 lbs.). These weaned baby pigs, called “isoweans” or “weaners,” next are taken to a nursery where they continue to grow for the next 6–9 weeks. Pigs in the nursery are called “nursery pigs.”

![Basic Flow Diagram](image)

*Figure 4.4. Swine basic flows in the Stella systems diagram simulation model.*
Today’s nurseries comprise one stage, meaning that pigs enter one room and stay there for the whole cycle (in the past there was a “hot” nursery and a “cold” nursery requiring additional movement of pigs). As pigs move out of the nursery at 8–12 weeks of age (50–80 lbs.) they become “feeder” pigs and then move to a finisher. Because these pigs will need 16–19 more weeks to reach market weight, as depicted in the above diagram, there must be two finishers for each nursery so that the nursery can continue to be regularly utilized/filled. Pigs in the finishers will then go to market at about 27–29 weeks (~6 months) of age weighing 250–280 lbs. The pigs in the finishers as well as those going to market are called finishers, market hogs, fat hogs, or fats. It is important to note that the term “finishers” can be utilized to refer to both the finishing buildings as well as the pigs in those buildings.

The third modified lecture was given four days after the second modified lecture. Additional systems-thinking material was provided from the farrowing PowerPoint slides (Appendix H, slides 34–61), and a new set of PowerPoint slides for the 4 circles evaluation, a new topic not covered in the previous year’s class (Appendix I), were provided and explained. In the “4 Circles Evaluation” slides, the instructor used the example of addressing pigs’ needs on the farm. Instead of using a standard checklist, he showed a technique that could identify issues more quickly in various and complex settings on different types of farms by analyzing the system using four circles. With a big-picture concept description, he illustrated the four-circle approach on a PowerPoint image slide. Starting with the biggest circle, he walked around the animal containment building and the entire site to get a first impression. Getting an overall view and also attending to details, he examined how well the owner maintained the building, equipment, and biosecurity. Next, for the second circle, he walked quickly through the building to get an impression before his body adapted to the
environment. For the second circle, he sought to gain perceptions about the overall and localized ventilation, the density of the stock, the general health of all the pigs, the maintenance of equipment, and the main problems of the herd. For the third circle, the instructor modeled examining one or more individual pens for possible issues. He made an overall pen assessment by checking the watering system, the feeders, differences in pig sizes, and signs of loose (scouring) pigs. Next he moved pigs around to evaluate their attitude and behavior upon seeing a human. In the final circle, he examined each individual pig with the presenting problem from head to tail and provided a complete evaluation at a distance. For this circle, he also distinguished individual pig problems from herd problems and selected individual pigs for necropsy to explore both individual and herd problems. Overall, the systems approach involved starting big (the overall system/widest circle) then progressively moving to a narrow focus. After conducting evaluations by way of the four circles, he provided the owner with recommendations consistent with his observations.

The last modified lecture was given in the third week of the 4-week swine course segment. At the beginning of this class, the swine Stella systems diagram simulation model as well as some simulations were demonstrated by the instructor. Without any PowerPoint slides, some system diagnostic questions related to the swine scenario corresponding to the Stella systems diagram simulation model were used to explain systems thinking. For example, one of the systems diagnostic questions concerned the average percentage of piglets currently affected with scours. Instead of directly telling students the systems diagnostic question, the instructor explained that most infected animals experience a feedback mechanism, i.e., if one piglet scour does that make more piglets scour? After a 35-minute lecture, students were given 15 minutes to complete the second online posttest.
Assessment instruments

Pretest and posttests. All instruments for Design Experiment 3 were finalized in early spring of 2013. The researcher created the three pre- and posttests online and sent them to the instructor a week before the class session. As with the two previous experiments, the web-based assessments consisted of case scenarios (four for Design Experiment 3) and, for each scenario, a list of diagnostic questions a veterinarian might seek to answer in diagnosing a particular health problem. The students were asked to select a set number of diagnostic questions as the best or most important to be answered first; they were not required to answer these questions. The scenarios described a veterinary health problem in a farming situation. The four scenarios presenting health problems involved goat Alopecia, swine piglet scouring, a food-safety chemical hazard, and a low-pregnancy beef cow issue (see Appendix J for copies of each assessment). The order of the scenarios and diagnostic questions were identical for all three pre-/posttests. However, there were minor differences between the two posttests for the beef scenario diagnostic questions. To prevent students from memorizing the systems diagnostic questions instead of understanding reasons for choosing them, the instructor who created the beef scenario modified some percentage numbers in the answers corresponding to the specific diagnostic questions (see Table 4.7). For example, the first diagnostic question (“Is the pregnancy percentage the same between the pastures?”) provided detailed information in the pretest: that “there were 19/86 (22.1%) open cows in Pasture 1, 10/109 (9.2%) open cows in Pasture 2, and 7/79 (8.9%) open cows in Pasture 3.” However, the percentage in the posttest was changed to “Pasture 1, 21/86 (24%) open; Pasture 2, 8/109 (7%) open; and Pasture 3, 7/79 (9%) open.” Although the percentages changed, there was no effect on the diagnostic question with respect to whether or not it was a systems question.
Table 4.7

*Beef Scenario Percentage Changes from Pretest to Posttest in the Diagnostic Questions*

<table>
<thead>
<tr>
<th>Pretest questions</th>
<th>Posttest questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (SQ) Is the pregnancy percentage the same between the pastures?</td>
<td>Pasture 1: 19/86 (22.1%) open</td>
</tr>
<tr>
<td></td>
<td>Pasture 2: 10/109 (9.2%) open</td>
</tr>
<tr>
<td></td>
<td>Pasture 3: 7/79 (8.9%) open</td>
</tr>
<tr>
<td>6. (SQ) What is the age profile and pregnancy distribution by age group in the herd?</td>
<td>Age % of herd % open</td>
</tr>
<tr>
<td>Age</td>
<td>% of herd</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>First-calf heifers</td>
<td>58/274 (21.2%)</td>
</tr>
<tr>
<td>Age 4–8 yr.</td>
<td>156/274 (41.8%)</td>
</tr>
<tr>
<td>Age &gt;8 yr.</td>
<td>60/274 (21.8%)</td>
</tr>
<tr>
<td>10. (NSQ) Did the body condition score differ by age?</td>
<td>84.5% of first-calf heifers were BCS 5 or greater</td>
</tr>
<tr>
<td></td>
<td>91.7% of cows 4-8 years old were BCS 5 or greater</td>
</tr>
<tr>
<td></td>
<td>95% of cows &gt; 8 years old were BCS 5 or greater</td>
</tr>
<tr>
<td>15. (SQ) What does the calving distribution of the herd look like?</td>
<td>90.5% of first-calf heifers were BCS 5 or greater</td>
</tr>
<tr>
<td></td>
<td>91.7% of cows 4–8 years old were BCS 5 or greater</td>
</tr>
<tr>
<td></td>
<td>91% of cows &gt;8-year-old were: BCS 5 or greater</td>
</tr>
</tbody>
</table>

Based on your pregnancy test results, we can divide the predicted calving into 21-day intervals (or periods) and plot the percentage of the herd that we expect to calve by period. Period 1 is the start of the calving season (March 1). Below is the chart representing this data.
Table 4.7 (continued)

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>16. (SQ) Is the calving distribution different by pasture?</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calving distribution differences by pasture are described in the charts below:</td>
<td></td>
<td></td>
</tr>
<tr>
<td><img src="image1" alt="Chart 1" /></td>
<td><img src="image2" alt="Chart 2" /></td>
<td><img src="image3" alt="Chart 3" /></td>
</tr>
</tbody>
</table>

| **17. (SQ) Is the calving distribution different by age group?** |         |          |
| Calving distribution differences by age category are described in the charts below: |         |          |
| ![Chart 5](image5) | ![Chart 6](image6) | ![Chart 7](image7) | ![Chart 8](image8) |
The percentage number changes from pretest to posttest in the diagnostic questions are listed in Table 4.7. The scenarios and accompanying diagnostic questions are described next.

The swine scenario was created in the fall of 2011 by the swine-specialist instructor for VDPAM 445. He developed the swine scenario and the list of diagnostic questions from an existing scouring piglets case. The chemical hazard scenario was created in the summer of 2012 by two poultry specialists who were postdoctoral associates at U of Ark working with a specialist at the USDA FSIS. These individuals were also team members on the HEC project. Using an existing antimicrobial residue case, they developed the chemical hazard case scenario and two lists of diagnostic questions to be selected from for the two subproblems. The beef scenario was created in the fall of 2011 by an instructor at KSU who specialized in beef (also a HEC project team member). He developed the scenario and the list of diagnostic questions to be selected using an existing heifer management case. More details are given below.

Changes made in the assessments after Design Experiments 1 and 2 were as follows. For the goat scenario, originally four diagnostic questions conforming to systems thinking were formulated for the first sub-problem and five were formulated for the second subproblem. However, some students were confused by the different numbers of diagnostic question to be chosen for each sub-problem during the pre- and posttest sessions in Design Experiment 2. One of the non-system diagnostic questions from the first goat scenario sub-problem was modified to be a systems-thinking diagnostic question. Therefore, for Design Experiment 3, each scenario sub-problem contained five systems-thinking diagnostic questions. Students were expected to select the five systems-thinking diagnostic questions from the list to address the problem in the scenario but not to answer them.
To improve the internal consistency of the swine scenario assessment, one system diagnostic question was modified due to the results of Cronbach’s coefficient alpha in Design Experiment 1. The original diagnostic question, “What is the average parity of the farms?” did not positively contribute to the internal consistency of the assessment. The question had been modified to “What is the average parity of the sows?” in Design Experiment 2 to increase the reliability of the assessment and was retained in that form for Design Experiment 3.

Because some students had taken courses with systems-thinking intervention prior to this course, the first question asked students to indicate whether they had previously taken, or were currently taking, any of the listed courses. Courses including systems thinking lectures included IE565, AER E 565, or E E 565 – Systems Engineering and Analysis; TSM 327 – Animal Production Systems; VDPAM 419x – Advanced Swine Production Informatics; VDPAM 310 – Introduction to Production Medicine; and VMPM 388 – Public Health.

Interview guides. The individual student and instructor interviews guides were designed to elicit insight into the cognitive impact of both the students’ and instructor’s experiences, as well as their reaction to the new instructional approaches for formative assessment and curriculum instructional development. The interview guide used for individual student interviews in Design Experiment 3 (Table 4.8) was expanded from the interview guide used in Design Experiment 2 (Table 4.4). The questions in the interview guide asked students to describe their general experiences on the systems-thinking approach during the four intervention lectures.

In addition, an instructor interview guide was created prior to the beginning of the semester (Table 4.9). The purpose of interviewing the instructor was to obtain feedback from
Table 4.8

_Interview Guide for the Students in Design Experiment 3_

0. Please tell me your name, class and your background

1. What is your experiences and reaction to
   a. The new instructional approaches (systems approach)
   b. Formative assessment (scenario and diagnostic question items)

2. Did you learn systems thinking in any form before this class?

3. We have 4 scenarios (goat, swine, chemical hazard, beef cow-calf); which ones did you learn?

4. How did you answer to scenarios that you did not learn? (apply what you have learned, intuition, sense, important, key points)

5. What have you learned about systems thinking from what Dr. R and Dr. P provided, included with the system thinking approach?

6. Do you plan a career in food-animal health management or something else?

7. What would you tell a friend about the ST (interpret the ST, feeling about utilizing the ST, easy or difficult to understand what the instructor was saying)?
   a. What are the things you liked most about learning using systems thinking?
   b. What are the things you liked least about learning using systems thinking?
   c. Would you recommend participation in systems thinking to colleagues at other institutions? Why?

8. Compare the systems approach and traditional teaching when learning similar content; which one is easier and why? Would you select a course using systems thinking over a course that did not?

9. What would you change about systems thinking teaching if you were the instructor?
   a. What materials would be helpful for the students learning the concept of systems approach.
   b. What practices could help the students to better demonstrate systems approach in the class.

10. What are your suggestions for creating scenarios with system diagnostic question items as well as assessing students’ understanding of ST?

11. Do you think about diagnoses differently now that you have done the ST training? Give an example of your thinking? (student’s in-depth thinking and reasoning processes)

12. Please provide any suggestions that you have for the individuals who are directing the systems thinking learning.

13. How else might you want to interact with the guest lecturers?

14. What is the best timing to learn ST?

15. Intervention amount right to you?

16. How long did it take you to complete the pre-, post1-, and post2-tests?

17. Suggestions or questions in general?
Table 4.9

*Interview Guide for the Instructor in Design Experiment 3*

1. What materials would be helpful for the instructor learning the concept of systems approach?
2. What practices could help the instructor to better demonstrate systems approach in the class?
3. What are the suggestions of creating scenarios with system diagnostic question items as well as assessing students’ understanding of ST?
4. What is the best timing to learn ST?
5. Did you ever learn systems thinking or similar form before Dr. [H]’s training sessions?
6. What are your suggestions in general?

the instructor’s point of view on learning, utilizing, and assessing the systems approach. The questions for the instructor’s interview guide asked what materials were helpful for the instructor in learning the systems-approach concepts, practices that could help the instructor better demonstrate the systems approach in class, and suggestions for creating scenarios with system diagnostic questions as well as assessing students’ understanding of systems thinking.

*Observation and data log.* The researcher observed the classes during the intervention and pre- and posttest class sessions. The researcher also used two video cameras mounted on tripods to record interactions between the instructors and students in the class. The front camera was used to record students’ reactions and the rear camera was used to record student activity during the lectures. In addition, the researcher used the iPod iTalk application to record the class discussion. Furthermore, the Echo 360 active learning and lecture capture solutions application was used to record the presentation appearing on the instructors’ computer screen. The Camtasia application was used to edit the recorded presentation videos after class sessions. Observations were noted in written logs during the intervention sessions and the pre- and posttests. Notes based on the video and audio recordings were added to the logs after the intervention and interviews.
In the logs the researcher recorded the following information in two parts—pre- and posttests and intervention lectures—as follows.

A. Pretests and posttests

1. Description of the participants for each test: the numbers of students (147), their gender (41 males and 106 females), and class year of the participants (all third-year students). These data were generated from Qualtrics.


3. Location: pretest (online outside of class) and posttest 1 and 2 (both taken in the classroom).

4. Students’ reactions to, interactions with, questions about, and problems regarding the pre- and posttests: most students did not finish the pretest in 10 minutes. The researcher noted that one third of students needed more time to complete the pretest and asked the instructor to stop the lecture and give students 5 extra minutes. The majority of the students were able to submit the test before the swine intervention. One student had trouble linking throughout the test and connected to posttest 1 later. Another student did not link to the test until after a 3-minute delay because he was working on something else. A few students chatted with classmates next to them at the beginning, then everybody became quiet while they worked on the test. A few students submitted the posttest 2 in 6 minutes, and half of the students finished in 10 minutes.
5. How many extra credit points given upon each test completion: 3 points for posttest 1 and 6 points for posttest 2.

6. Researcher’s reflection of the pre- and posttests: There were four scenarios in the pre- and posttests. Students needed at least 15 minutes to complete each test. If the instructor was not able to provide enough time for student completion in the class, an online test before the intervention should be arranged. However, for an online test some variables, such as duration of the test, peer discussions, and searching information online, might not be able to be controlled. Students who filled out the test after the swine intervention should not be included in the analysis.

B. Intervention lectures

1. Description of the participants: class year of the participants for each lecture (all third-year students).

2. Dates (first lecture: Mar. 8; second lecture: Apr. 8; third lecture: Apr. 12; fourth lecture: Apr. 24), starting and ending times (first lecture: (9:00–9:10 a.m.; second lecture: 9:40–9:50 a.m.; third lecture: 9:00–9:50 a.m.; fourth lecture: 9:00–9:40 a.m.), duration (first lecture: 12 minutes; second lecture: 10 minutes; third lecture: 50 minutes; fourth lecture: 35 minutes).

3. A description of class activity of the systems trainer and graduate assistant who delivered the interventions:

   a. First lecture: The goat instructor provided a 5-minute introduction on systems thinking and the systems assistant demonstrated the goat Stella
systems diagram simulation models for another 5 minutes. There was no use of PowerPoint in this intervention.

b. Second lecture: The swine instructor introduced the swine session for 10 minutes, released the posttest 1 link for students to complete during class time, started the general swine lecture after students completed posttest 1, and then introduced systems thinking during the last 10 minutes of the class. The PowerPoint material used was same as for Design Experiment 1.

c. Third lecture: The swine instructor presented a new concept of systems thinking called “4 Circles Evaluation” in addition to the previous year’s PowerPoint presentation for 50 minutes.

d. Fourth lecture: At the beginning of the class, the swine instructor invited students to volunteer for interviews. The researcher then passed out a sheet for interview volunteers to fill in their name and contact information. In the first 35 minutes of the class, the instructor demonstrated swine Stella systems diagram simulation models without discussing the diagnostic questions.

4. Students’ reactions to, interactions with, questions about, and problems regarding the instruction during the interventions and Stella systems diagram simulation model. In the fourth lecture, some students listened to the instructor’s explanation but some worked on other tasks, such as e-mail, because the Stella systems diagram simulation model was not posted on the blackboard—it was shown only on the front screen. One student asked a question about the distance between two sites that might increase the risk of disease.
5. The researcher’s reflection of the interventions how many lectures, length of time taken for the intervention in each lecture, and how frequently the intervention was given are important aspects for students to fully understand and apply systems thinking to problem solving; length and duration of the intervention are also factors; more practice is necessary.

As noted above, the written logs consisted of the dates, start times, end times, and durations for the interventions and pre-/posttests; special cases, such as students who spent more than an hour or less than one minute to complete the pretest or submitted the same test, either pretest or posttest, more than once, which showed instantly on Qualtrics; reactions to, interactions with, questions about, and problems regarding the instruction during the interventions, Stella systems diagram simulation models, and the pre- and posttests; a description of what instructors and the systems graduate assistant delivering the interventions did during the class sessions; a list of interview volunteers’ names, available times, and a list of email addresses passed around during the last lecture by the researcher; the numbers, gender, and class year of the participants, which appeared on Qualtrics for each test; the context, outline, and content of the lectures; the instruments used in the lectures, such as PowerPoint, pre- and posttests, and Stella systems diagram simulation models; the number of extra credit points given for test completion; and the researcher’s reflection of the intervention and pre- and posttests.

**Procedure.** Design Experiment 3 was conducted during the Spring 2013 semester from January 14 to May 3. The experiment was conducted in two parts of the course taught by different instructors. The first part of intervention was held during the ruminant segment of the class. The second part of intervention was held during the swine segment of the class.
Students completed a pretest assessing their understanding of systems thinking, received instruction on systems thinking specifically on the goat scenario 2 weeks later, completed the first posttest 4 weeks after that, received instruction on systems thinking specifically on the swine scenario immediately after the first posttest, and after 2 weeks, completed the second posttest immediately after instruction on systems thinking specifically on the swine scenario at the end of the course.

**Pretest.** In the 5th week of the first segment, 3 weeks before the first intervention class session, students were assigned to complete the web-based pretest outside of class sometime between Feb. 13 and Feb. 20. The test included the four scenarios described above in the assessment discussion. The instructor posted the URL of the pretest on Blackboard CMS just before the class started. Over a period of 10 minutes at the beginning of the class session, he introduced a particular systems-thinking project, the researchers involved, and noted the link to the pretest. He announced that students were to complete the pretest within 6 days. Within the 6-day interval, students had no a time limit for completing the pretest. He then began teaching course materials that did not include systems thinking.

**First intervention session.** The first intervention session was held during the first 12 minutes of the ruminant section class on Mar. 8. In the eighth week of the first segment, the goat instructor spent 6 minutes introducing the systems approach using an example of type II ketosis in dairy cattle and mentioned the goat dairy alopecia scenario without showing any systems-thinking PowerPoint slides. The systems graduate assistant then demonstrated the goat Stella systems diagram simulation model. He described the animal flow through the agricultural operation and the key disease processes relevant to the goat dairy alopecia scenario. After the 12 minutes of intervention, another instructor began to teach a different
subject—the GI system—for the remainder of the 38-minute time period; no systems approach content was included in the GI system lecture.

**Posttest 1 and second intervention session.** On Apr. 8, posttest 1 was given and the second intervention session began in the swine section of the course. The second segment of the VDPAM 445 course was started in the 13th week of the semester. In the first week of the second segment, the course instructor posted the first posttest link on Blackboard after giving a 10-minute general introduction to the swine segment. The instructor included the course overview, swine practice, and production systems in his introduction PowerPoint slides. The swine session focused on the structure and function of swine practice, necessary skills and approaches to problem solving, rule-out lists, and diagnosis and treatment. The schedule, readings, course management systems-WebCT, contact information and office hours were also covered. Students were then given 15 minutes to complete posttest 1 in class. In the remaining 25 minutes of the class, the students received an intervention lecture incorporating systems thinking. The lecture covered swine background information, a five production input fishbone diagram for piglet diarrhea, and systems-thinking concepts. Using PowerPoint slides 8–33 (Appendix H), the instructor explained how systems thinking could be used for problem solving and communication. Basic flows of the five production inputs in the swine Stella systems diagram simulation model were shown and discussed.

On April 12 and 24, as part of the second intervention, the students received two additional lectures on the systems approach as applied to swine. A 50-minute systems-approach swine intervention that specifically included systems thinking was given on April 12 using PowerPoint slides 34-61 (Appendix H), continuing the lecture for April 8 with a new set of PowerPoint slides (see Appendix I, slides 1–16). The instructor continued the
lecture on swine production phases; performance measures for growing pigs; and an overview of nutrition, facilities, and husbandry, food safety/meat quality, welfare issues, mortality spiral, and the 4-circle evaluation method. The systems approach involved starting big (the overall system/widest circle) then progressively narrowing the focus. A 35-minute systems-approach swine intervention, including the swine Stella system diagram model, was given on April 24. At the beginning of this class, the instructor demonstrated the model along with some simulation examples. Without using PowerPoint slides, some system diagnostic questions from the swine scenario corresponding to the Stella systems diagram simulation model were used to explain systems thinking. The swine scenario and its Stella systems diagram simulation model were covered in these lectures. Students were taught the basic concepts of systems thinking and Stella systems diagram simulation modeling using the swine scenario.

**Posttest 2.** The second posttest was given during the final 15 minutes of the Apr. 24 class session. The instructor posted the link for the posttest on the Blackboard CMS. Students used their laptop computers to log on to the website and complete the posttest.

**Interviews.** After posttest 2, the researcher scheduled and completed 60-minute individual interviews with each of the six students and the swine instructor using the interview guide described earlier (Tables 4.8 and 4.9). The interviews were conducted individually with each student and with the instructor to avoid the distraction of influence from others. Individual interviews also allowed the researcher to better understand students’ thinking and reasoning processes. Students could also explain more details of their understanding of systems thinking. An iPod iTalk application was used to record the interview conversations. The researcher also took notes while interviewing the students and instructors. The timeline for Design Experiment 3 is shown in Table 4.10.
Table 4.10
Timeline for the Intervention Procedure in VDPAM 445 (Design Experiment 3)

<table>
<thead>
<tr>
<th>Date(s)</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb 13-20</td>
<td>Out of class online pretest (138 = 147 – 9 absents)</td>
</tr>
<tr>
<td>Mar 8 (Fri)</td>
<td>Goat intervention</td>
</tr>
<tr>
<td>Apr 8 (Mon)</td>
<td>In-class posttest 1 &amp; swine intervention 1 (133 = 147 – 8 absent – 6 submit after class)</td>
</tr>
<tr>
<td>Apr 12 (Fri)</td>
<td>Swine intervention 2</td>
</tr>
<tr>
<td>Apr 24 (Wed)</td>
<td>Swine intervention 3 &amp; in-class posttest 2 (127 = 147 – 20 absents)</td>
</tr>
<tr>
<td>Apr 24-May 5</td>
<td>Interview: 6 female students and 1 faculty</td>
</tr>
</tbody>
</table>

**Statistical analyses.** Quantitative data were analyzed using the SPSS computer package. Scores on the pretest and posttests were first analyzed using the SPSS scale reliability analysis and the GLM repeated measures ANOVA procedure. Descriptive statistics, such as frequencies, mean averages, standard deviations, and percentages, were generated. One-way ANOVA models were computed to determine differences among the tests (pretest, posttest 1, and posttest 2). Bonferroni confidence interval adjustment for main effects’ pairwise comparisons in ANOVA were computed to determine whether students’ scores were higher on posttest 1 than on the pretest, higher on posttest 2 than on the pretest, or higher on posttest 2 than on posttest 1. Second, a reliability test was conducted and the Cronbach’s coefficient alpha values for each diagnostic question and each scenario question between the three pre-/posttests was analyzed to determine whether the testing scale was reliable. Third, exploratory factor analysis using maximum likelihood estimation were conducted to attempt improvement in the reliability of diagnostic questions.

The changes in the pre-/posttests’ results between Design Experiment 1 and Design Experiment 3 also were compared to determine whether class cohort played an important role.
in the tests. To determine whether there were differences in performance of students in these two classes, a mixed (between/within) ANOVA model was estimated using class (Design Experiment 1 versus Design Experiment 3) as the between-subjects variable and time of testing (pretest, posttest1, posttest2) as the within-subjects variable.

The qualitative data were collected from the six students and one instructor via individual interviews and from observations made during the interventions and the tests taken in the classroom. The procedure for the qualitative data analysis was the same as for Design Experiment 2, for which interviews were analyzed using the NVivo 10 application computer program and qualitative analysis strategies (e.g., coding and categorization) were used. The data were transcribed from audio-recorded interviews and entered into the Microsoft Word and Microsoft Excel spreadsheet programs.

Results

Quantitative results. Recall that 34 students out of the original 147 completed at least one, but not all three, assessments (pretest, posttest1, posttest2). In addition, four students submitted posttest 1 late. Thus 109 students completed all three assessments and followed the required timeline. To ensure that the missing data from the students who did not complete all three assessments did not substantially affect the results, for each test, the performance of students who completed all three tests was compared to the performance of students who had completed the given test, but not all three. For each of the tests, the differences between the two groups of students were not significant. The results of these comparisons are presented in Appendix K.

In addition, among the 109 students completing all three tests, some students had been exposed to systems thinking in previous classes. Four students had taken VDPAM 419x during the Fall 2012 semester and 51 students had taken VDPAM 310 – Introduction to
Production Medicine (classification as second- or third-year Veterinary Medicine student) during the Spring 2013 semester, but two students who had taken both VDPAM 419x and VDPAM 310 were included in both counts. Thus, 53 students had received extra instruction related to the systems approach. As a preliminary check to determine if these students behaved differently than students receiving the systems approach for the first time, the performance of these two groups of students on the pre- and posttests were compared. There were no significant differences, so the data were combined for the overall analyses. The results of these analyses are presented in Appendix L.

It had been hypothesized that student performance would improve across the span of these three assessments (pretest, posttest1, posttest2). To assess this hypothesis, repeated measures ANOVA models were estimated, comparing the pretest, posttest1, and posttest2 total percentage of correct scores using the SPSS GLM procedure. The mean percentage of correct answers and standard deviations on the pre- and posttests is summarized and the ANOVA results are presented in Table 4.11. As can be seen in Table 4.11, consistent with the hypothesis, performance improved significantly across the three tests, $F(1,108) = 38.1$, $p < .001$, $MSE = 35.6$, partial $\eta^2 = .27$. To determine which test results were significantly different from the others, the multiple comparison option in GLM was selected using the Bonferroni adjustment as part of the ANOVA. The multiple-comparison results are summarized in Table 4.12. Results from each of the tests were significantly different than the results from the other two tests. That is, performance improved significantly from pretest to posttest 1 and posttest 2 and from posttest 1 to posttest 2. These data suggest that students improved in their ability to select systems questions during the instruction.
Table 4.11
Mean Percentage Correct, Standard Deviations, Standard Errors of the Mean, 95% Confidence Intervals, and Number of Participants in Design Experiment 3

<table>
<thead>
<tr>
<th>Design Experiment 3</th>
<th>M</th>
<th>SD</th>
<th>SEM</th>
<th>95% CI</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest***</td>
<td>40.39a</td>
<td>6.63</td>
<td>.64</td>
<td>39.16-41.63</td>
<td>109</td>
</tr>
<tr>
<td>Posttest 1***</td>
<td>44.59b</td>
<td>7.29</td>
<td>.70</td>
<td>43.22-45.95</td>
<td>109</td>
</tr>
<tr>
<td>Posttest 2***</td>
<td>47.50c</td>
<td>8.15</td>
<td>.78</td>
<td>45.94-49.05</td>
<td>109</td>
</tr>
</tbody>
</table>

Note. ANOVA repeated measures for pretest to posttest1 to posttest2 correct percentage, with Bonferroni adjustment (Bf), p < 0.0167.

abcMeans with different superscripts are significantly different at p < .0005 when tested with the SPSS multiple comparison procedure with Bonferroni adjustment.

Table 4.12
Significant Differences Among the Pretest, Posttest1, and Posttest 2

<table>
<thead>
<tr>
<th>Tests I, J compared</th>
<th>Mean difference (I – J)</th>
<th>SE</th>
<th>Sig. a</th>
<th>Cohen's d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest 1 – Pretest</td>
<td>4.19*</td>
<td>.79</td>
<td>&lt;.001</td>
<td>.60</td>
</tr>
<tr>
<td>Posttest 2 – Pretest</td>
<td>7.10*</td>
<td>.83</td>
<td>&lt;.001</td>
<td>.96</td>
</tr>
<tr>
<td>Posttest 2 – Posttest 1</td>
<td>2.91*</td>
<td>.80</td>
<td>&lt;.001</td>
<td>.38</td>
</tr>
</tbody>
</table>

Note. Based on estimated marginal means.

aAdjustment for multiple comparisons: Bonferroni.

*Mean difference is significant at the .05 level.

Although the results with respect to the total posttest score demonstrate that students improved their performance from pretest to posttest, it’s important to know whether the students were able to transfer their improved ability to use systems from the topics taught in these courses to other topics. The students had received the instructional innovation applied most directly to goat and swine topics. Were they to show improved performance on other topics, that finding would provide evidence of transfer to new topics. Therefore the patterns of performance across the assessments for each of the multiple topics were examined. In
other words, repeated measures ANOVA was conducted on each of the problems and subproblems on the assessments—goat1, goat2, swine, chemical1, chemical2, and beef. The students had received direct instruction on the goat1, goat 2, and swine instructional scenarios, but not on the others. Thus, improvements in performance from pretest to posttest for goat1, goat2, and swine would represent direct learning; any improvement on the other scenarios would represent some degree of transfer.

The results of these analyses are summarized in Table 4.13. As shown, significant and substantial improvements from pretest to the posttests were found for the goat1 and swine scenarios, which were most directly related to the systems-approach instruction. In addition, evidence of transfer was found for the beef scenario, on which performance improved significantly from pretest to posttest 1 and from posttest 1 to posttest 2. The size of these effects were respectable: time of testing (pretest, posttest 1, and posttest 2) accounted for about 11% of the variance for goat1, 30% of the variance for swine, and 37% of the variance for beef. On the other hand, there were no significant effects for the goat2, chemical1, and chemical2 scenarios. Cohen’s $d$ values for each of the significant contrasts between the tests (pretest–posttest1, pretest–posttest2, and posttest1–posttest2) are presented in Table 4.14. The Cohen’s $d$ values represent changes in the moderate to stronger effects ranges.

Part of the responsibility inherent in new instructional projects is to develop effective assessments with respect to new knowledge. Therefore, basic psychometric analyses of the pretest, posttest1, and posttest2 were conducted. Using the SPSS internal consistency scale procedure, Cronbach’s coefficient alpha reliability coefficients were computed for the total pretest and posttest scores by using the percentage correct on each of the subtests (goat1,
Table 4.13

Mean Percentages Correct, Standard Deviations, and Summary of the Repeated Measures ANOVAs on the Subtests of the Pre- and Posttests in Design Experiment 3

<table>
<thead>
<tr>
<th>Scenario</th>
<th>MSE</th>
<th>F, Sig.</th>
<th>Pretest</th>
<th>Posttest 1</th>
<th>Posttest 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>% Crt</td>
<td>SD</td>
<td>% Crt</td>
</tr>
<tr>
<td>Q1 goat1</td>
<td>269.2</td>
<td>6.90</td>
<td>.060</td>
<td>22.2^A</td>
<td>16.4</td>
</tr>
<tr>
<td>Q2 goat2</td>
<td>231.4</td>
<td>2.62</td>
<td>.075</td>
<td>39.3</td>
<td>17.2</td>
</tr>
<tr>
<td>Q3 swine</td>
<td>200.9</td>
<td>24.06</td>
<td>.001</td>
<td>28.1^A</td>
<td>14.7</td>
</tr>
<tr>
<td>Q4 chemical1</td>
<td>245.9</td>
<td>1.51</td>
<td>.223</td>
<td>29.5</td>
<td>17.1</td>
</tr>
<tr>
<td>Q5 chemical2</td>
<td>135.5</td>
<td>0.28</td>
<td>.756</td>
<td>68.3</td>
<td>14.5</td>
</tr>
<tr>
<td>Q6 beef1</td>
<td>117.9</td>
<td>34.77</td>
<td>.001</td>
<td>47.7^A</td>
<td>11.8</td>
</tr>
</tbody>
</table>

^a% Crt: Mean percentage of system questions correctly selected.

^bDegrees of freedom = 2, 107 for each analysis.

^A,B,C Means with different superscripts are significantly different, p < .05.

...goat2, swine, chemical1, chemical2, and beef) as the items. The Cronbach’s coefficient alpha coefficient values for the three tests indicate a weak level of internal consistency: pretest Cronbach’s coefficient alpha = .183; posttest1 Cronbach’s coefficient alpha = .32; and posttest2 Cronbach’s coefficient alpha = .473. Low reliabilities are to be expected on a...
Table 4.14
*Cohen’s d for Each of the Significant Mean Contrasts in Design Experiment 3*

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mean contrasts</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest–posttest1</td>
<td>Pretest–posttest2</td>
<td>Posttest1–posttest2</td>
<td></td>
</tr>
<tr>
<td>Goat1</td>
<td>0.37</td>
<td>0.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swine</td>
<td>0.36</td>
<td>0.93</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>Beef</td>
<td>0.77</td>
<td>1.13</td>
<td>0.35</td>
<td></td>
</tr>
</tbody>
</table>

pretest if students have little knowledge of the subject and are just guessing; the pretest Cronbach’s coefficient alpha value reflects a very low level of internal consistency. The internal consistency values for the posttests show improved internal consistency, but still reflect low levels of consistency substantially below typically acceptable levels (e.g., .7 or above for research tests). These results suggest that the quality of the assessments should be improved in future implementations of their use for evaluating the systems approach in Veterinary Medicine classes.

To attempt to improve the reliability, an exploratory factor analysis using principal component extraction with varimax rotation was conducted using the six subtest scores from posttest2 as data. Two factors emerged with eigenvalues greater than 1. Factor 1 (with an eigenvalue of 1.696) accounted for 28% of the variance, and Factor 2 (with an eigenvalue of 1.161) accounted for 19.4% of the variance (Table 4.15).

We computed internal consistency Cronbach’s coefficient alpha scores on the factor scores by summing the high-loading subtests for each factor. For Factor 1 score, Cronbach’s coefficient alpha = .475, whereas for Factor 2 score Cronbach’s coefficient alpha = .08. There was no improvement in reliability as a result of utilizing the factor scores. We also estimated repeated measures ANOVA models on scores derived by summing the subtest
Table 4.15

Factor Loadings for Each of the Six Sub-Problem Scenarios on Posttest 2

<table>
<thead>
<tr>
<th></th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>1.696</td>
<td>1.161</td>
</tr>
<tr>
<td>% of variance</td>
<td>28.3</td>
<td>19.4</td>
</tr>
</tbody>
</table>

Rotated factor loadings$^a$

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest 2.4: Chemical1 % Crt</td>
<td>0.713</td>
<td>−0.028</td>
</tr>
<tr>
<td>Posttest 2.1 Goat1 % Crt</td>
<td>0.636</td>
<td>0.288</td>
</tr>
<tr>
<td>Posttest 2.3 Swine % Crt</td>
<td>0.575</td>
<td>−0.414</td>
</tr>
<tr>
<td>Posttest 2.2 Goat2 % Crt</td>
<td>0.558</td>
<td>0.388</td>
</tr>
<tr>
<td>Posttest 2.6 Beef1 % Crt</td>
<td>−0.005</td>
<td>0.699</td>
</tr>
<tr>
<td>Posttest 2.5 Chemical2 % Crt</td>
<td>0.138</td>
<td>0.625</td>
</tr>
</tbody>
</table>

$^a$% Crt: Mean percentage of system questions correctly selected.

scores from factor 1 and factor 2. These ANOVAs provided results similar to the total scores above; performance improved from pretest to posttests in both ANOVAs. For the Factor 1 scores, performance also improved from posttest1 to posttest2, but did not for Factor 2. The full summaries of these ANOVAs are presented in Appendix M.

The Cronbach’s coefficient alpha value for each of the subtests also was computed. Across each of the subtests, the Cronbach’s coefficient alpha value was negative, indicating that the systems questions on each sub-problem scenario might be correlated negatively with one another on average, or a coding error - negatively worded systems questions. The negative Cronbach’s coefficient could also caused by the small sample size. These results further suggest that there are substantial problems with the reliability of the assessments used
in Design Experiment 3. Table N.3 - Table N.14 present the Cronbach alphas for each of the sub-problem.

Four diagnostic questions were common to the swine scenario for students in Design Experiment 1 (VDPAM 445, Spring 2012 semester) and students in Design Experiment 3 (VDPAM, Spring 2013 semester). This allows for a comparison of the performance of students from Design Experiment 1 and Design Experiment 3. This comparison is of interest because changes were made to increase the amount of class time devoted to the systems approach for Design Experiment 3. To determine whether there were differences in performance among students in these two classes, a mixed (between/within) ANOVA model

Table 4.16
Mean Percent Correct and Standard Errors of the Mean on the Pretest, Posttest1, and Posttest2 for the Students in the Swine Section of VDPAM 445 in Design Experiment 1 and Design Experiment 3

<table>
<thead>
<tr>
<th>Class</th>
<th>Time</th>
<th>M</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined (N = 221)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>34.05</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>Posttest1</td>
<td>41.52</td>
<td>1.27</td>
<td></td>
</tr>
<tr>
<td>Posttest2</td>
<td>47.96</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td>Design Experiment 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>33.93</td>
<td>1.81</td>
<td></td>
</tr>
<tr>
<td>Posttest1</td>
<td>41.96</td>
<td>1.79</td>
<td></td>
</tr>
<tr>
<td>Posttest2</td>
<td>48.21</td>
<td>2.04</td>
<td></td>
</tr>
<tr>
<td>Design Experiment 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>34.17</td>
<td>1.82</td>
<td></td>
</tr>
<tr>
<td>Posttest1</td>
<td>41.06</td>
<td>1.82</td>
<td></td>
</tr>
<tr>
<td>Posttest2</td>
<td>47.71</td>
<td>2.07</td>
<td></td>
</tr>
</tbody>
</table>
was estimated using class (Design Experiment 1 versus Design Experiment 3) as the between-subjects variable and time of testing (pretest, posttest 1, posttest 2) as the within-subjects variable. Performance improved significantly from the pretest to posttest 1 and from posttest 1 to posttest 2 in both classes, $F_{time}(2, 436) = 24.46, p < .001, MSE = 287.12$, partial $\eta^2 = .101$. However, there were no significant effects of class or interaction between time and class, $F_{class}(1, 218) = .006, p < .937, MSE = 611.1$, partial $\eta^2 = .000; F_{interactions}(2, 436) = .06, p < .94, MSE = 287.12$, partial $\eta^2 = .000$ (Table 4.16, Table 4.17). Further results are presented in Appendix O.

Table 4.17
Pairwise Comparisons for Pre-post1-post2 tests, Class 2013-2014 Data Combined

<table>
<thead>
<tr>
<th>Time (I)</th>
<th>Time (J)</th>
<th>Mean difference (I – J)</th>
<th>SE</th>
<th>Sig. $^a$</th>
<th>95% confidence interval for difference $^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posttest1</td>
<td>Pretest</td>
<td>7.46</td>
<td>1.42</td>
<td>&lt;.001</td>
<td>4.02 to 10.89</td>
</tr>
<tr>
<td>Posttest2</td>
<td>Pretest</td>
<td>13.91</td>
<td>1.68</td>
<td>&lt;.001</td>
<td>9.87 to 17.95</td>
</tr>
<tr>
<td>Posttest2</td>
<td>Posttest1</td>
<td>6.45</td>
<td>1.72</td>
<td>.001</td>
<td>2.3 to 10.6</td>
</tr>
</tbody>
</table>

**Qualitative findings.** The qualitative analysis comprised two parts: the student interviews and the instructor interview.

**Student interviews.** The findings for the student interviews focused on three major issues: (a) the degree of students’ understanding of systems thinking, (b) students’ ability to transfer knowledge to a new field, and (c) students’ concerns about learning and teaching systems thinking. Questions on students’ interpretation of systems thinking and suggestions for teaching and assessment were related to the degree of students’ understanding of systems thinking (see questions 7, 9, and 10 in Table 4.8). The questions on students’ ability to
provide examples of applying systems thinking from one field to another related to their ability to transfer knowledge (see questions 4 and 11 in Table 4.8). A set of questions on learning and teaching systems thinking were related to students’ concerns (see questions 1, 12, and 17 in Table 4.8).

As discussed previously, interviews were conducted with six students. All six participants were third-year female students. In each interview, instruction was given to the participants about the process. Questions were read to each participant. For purposes of anonymity, each student was given an alphabetical code. Students H, I, J, K, L, and M are all female students.

After the qualitative data collection, audio files were transcribed and entered into a Microsoft Word file on the researcher’s personal laptop computer. The transcript data were organized by participant and question. Students’ responses were reviewed multiple times to identify the emerging themes: understanding, transferring, concerns.

This section includes a summary description of student responses, illustrative quotes from the individual interview data, and an interpretation. For the second theme, transferring, the key items posed were related to: (a) examples of students telling a friend, (b) their experiences and reaction to the formative assessment on beef cow-calf and chemical wizard scenarios, (c) students’ background and tracking, (d) previous experiences with systems thinking in any form before the intervention lectures, and (e) how students’ responded to scenarios from which they did not learn. For the third theme, students’ concerns on learning systems thinking were discussed through the use of three items: (a) experiences and reactions to new instructional approaches, (b) the best timing to learn systems thinking, and (c) general suggestions or questions.
Understanding of systems thinking. Data for the first theme, understanding, was gathered from responses eight items: (a) tell a friend about systems thinking, (b) modify teaching if you were the instructor, (c) right amount of intervention, (d) suggestions for creating scenarios with system diagnostic question items as well as assessment, (e) time duration to complete the pretest and two posttests, (f) increasing interactive learning on systems thinking, (g) thinking differently about diagnosis, and (h) comparing the systems approach with traditional teaching. The degree of students’ understanding of systems thinking was characterized based on the following experiences shared during the individual interview sessions.

From the interviews, it was discovered that most students had not learned systems thinking prior to this class, as illustrated by the following comments:

This . . . probably . . . has been my first in-depth introduction to it. (student I)
No, never in my undergrad . . . I’ve never learned it officially in a course. (student J)
No, [I did not learn systems thinking]. (student K)
Not in a formal sense, no. (student L)
No. It’s definitely the first time [learning systems thinking]. (student M)

However, all six participants claimed that the idea of systems thinking was not new to them because it was either taught in other courses, such as food-animal, beef-record, case-studies, and other swine classes before or concurrently with this class, or used in previous agriculture or production jobs. The students noted:

What was presented I didn’t really find new to me because I’ve been around agriculture . . . so much of agriculture is industrialized and confinement-based. You know everything you do on a farm affects the other components, so that was
something we discussed a lot [in undergrad]. . . . I’m not sure if there’s an aspect of
the food-animal curriculum that is not being taught that way. I think it’s been pretty
comprehensive in our food-animal class. (student H)

This way of thinking, of identifying all the factors that are playing into this animal or
this diseases is . . . like identifying nutrition and identifying you know what is the
environment that this animal is living in and what is its social stimulation and what is
its interaction with other animals. So it’s something that people are already doing,
and I think I realize that the more we did it . . . this is just a more formalized way of
looking at it and applying it. . . . People . . . are probably already using some parts of
it but don’t realize that. . . . We’ve now given it a structure and a name. (student I)

We already take a course, case studies, during fall of our second year . . . [that] just
[teaches] us how to ask the right question, and we feel like as we go along, we’ve
already learned that kind of thing. . . . They focus on getting a pertinent history and
asking the right questions. (student K)

We have a couple electives here with learning how to use two different ratios to
understand the systems. . . . I’ve already kind of thought that way. So it wasn’t that
hard of a jump. . . . I’ve taken a couple beef records classes, so that helps. (student L)
We need to not only just focus on infectious agents, we need to look at the bigger
picture too. . . . I already kind of have that mindset. . . . I also got some of this from
Dr. [K] in VDPAM 310 [concurrently in this semester]. So I’ve gotten it in both
places. . . . I’ve been using it . . . and I think professors and veterinarians emphasize it
without saying it. (student J)

I heard the name “systems thinking” before taking this class. (student M)
Although student K indicated that systems thinking was not new to her, she did not know what it was, asking during the interview: “Well why don’t you tell me what systems thinking is since I apparently don’t know what it is.”

Three students thought they made diagnostic decisions differently after the intervention lectures and the pre- and posttests.

After [the systems approach] lecture this week, I realized that it was maybe more important to find out how the animals were grouped, and how those groupings were set up, and where animals traveled to different groupings. Especially in the swine scenario . . . the movement of animals in different areas and those groupings, and stressing that were on them in each area were probably the key to understanding what was going on. . . . I do [diagnosis decisions differently now]. . . . I do think that the more you can broaden your vision to understand the factors that are influencing it, the more effective you’re going to be long term, and also the more effective you’re going to be either with the owner or the producer, because you’re going to be making . . . change . . . [with] the diet or the environment . . . [and helping] them more long-term than just fixing this one particular problem they’re having. . . . The more that I learn about it, the more I can see how it applies almost beyond just production animal systems. (student I)

I think [I made diagnosis decisions differently after intervention lectures]. (student M)

However, Student L did not claim to make diagnostic decisions differently. She claimed her decisions were based on previous knowledge and were no different after the systems-approach intervention lectures, saying:
I’ve always thought in the systems approach to begin with . . . I think more thorough, but I don’t think I would have done anything differently through a systematic approach. . . . I don’t really think there would be a difference. (student L)

Student J also did not perform diagnoses differently after intervention lectures. She thought that it would come with the time in the fourth year when she actually began to have hands-on experience. The systems approach helped her identify instead of diagnose the problem:

[The systems approach] helps us to better identify what the causative agents for example might be, on top of managerial aspects. . . . We could say, it’s E. coli, it’s salmonella, it’s rotavirus, it’s crypto . . . respiratory. . . . The issue wasn’t so much how do we diagnose it. That will come with time . . . when we actually put our hands-on fourth year . . . it’s more of the identifying. . . . Now that I have knowledge from other courses in the systems approach, I can identify, is it coming from the environment, or . . . the milker’s hands . . . from other cattle who aren’t vaccinated . . . from the cow itself? . . . I would like to do a test to see if it was E. coli versus, I would do test blah-blah-blah, and list them all off. . . . That comes much more fourth year. That’s more real life, downstairs, when they take us out on calls on consulting work. Even small animal. . . . It’s got an affected joint. Well, it could be any number of things. . . . I don’t [think I diagnosis differently] . . . that’s not so important.

(student J)

However, student J did believe her systems-thinking ability was enhanced after intervention lectures, as she noted, “Having [the instructors] explain it much more . . . helped guide me to go, ‘Okay, I was still a little even still too focused on infectious disease, it could have been way more managerial’ (student J).
Students spent approximately 15–60 minutes to complete the pretest and posttests and would have liked to have more time to complete them in class or outside of class. Student H spent probably 20 to 30 minutes on the pretest at home. She wished she had more time to look at the graphs in the beef scenario because she didn’t have enough time to read everything on the tests and think about it in the class. She also provided suggestions for improving the test format and design, for example, providing more space on the screen and picking five instead of 10 diagnostic questions in the beef scenario. Student I spent 12–13 minutes on the pretest at home and less time for the posttests in class. She was a fast reader and recognized the same questions in the posttest that were used in the pretest. Student K spent 10–15 minutes on each of the tests. Student L spent 20–30 minutes to just process the pretest at home and 15 minutes rapidly skimming and analyzing the posttests in the class. She thought her posttest answers were not as well thought through as those for the pretest. Student J spent a maximum of 15 minutes on the tests and less time on the posttests than on the pretest. Student M spent 1 hour on the pretest and 30 minutes on the posttests. She was rushed in answering the last question during the posttests in the class. These students’ comments about taking the tests were as follows:

In class I took 10 minutes [for the posttests] . . . because there was pressure to finish from the professor. . . . I had seen the questions before so that helped, but I really should have taken more time on the beef section for sure to look at all the graphs. . . . You need 20 to 30 . . . especially if you’re seeing it the first time. . . . When we did it in class, we really didn’t have enough time to read everything and think about it. When we did it on our own it was fine. . . . If you did it in class you might need to make the test shorter, just because you don’t want to take class time. Otherwise it
It would be better to have students do it outside of class. . . . It would be nice to have more space on the screen. . . . I found it very hard to read and that made me kind of rushed somehow . . . I couldn’t see all the questions spaced out. . . . The one scenario where you were supposed to pick 10 questions, that was a lot . . . you couldn’t even see the whole question on one screen, so you were constantly scrolling back and forth to try to remember which questions you had already selected. . . . It would [be] better . . . to either find a different format or to only have to choose five questions. . . . [Making the font size smaller] would be hard to read. . . . Maybe just make all the scenarios like the others where you had 10 questions total, and you only had to pick five. I think that’s much easier to keep in your head—because don’t they say like you can only memorize seven things in short term? So if you have to keep track of 10 questions that you’re supposed to choose, plus look at 10 others, I don’t feel like I can do a good job without sitting down and writing everything out. (student H)

It might have been 20 minutes to a half hour just to process [the pretest at home] . . . it might have been 15 minutes [for the posttest in the class] . . . because I was kind of starting to skim. But I might have missed a lot because I was trying to work faster . . . I skipped a lot more (for the second posttest in class) and tried to fill it out. . . . I finished it in . . . 10 to 15 minutes because I was analyzing each question and trying to see all the different types of information that I’d get from each question and then ranking them. . . . 15 minutes to a half hour is probably my optimal time . . . I’m less rushed at home than in the class. So I don’t feel like my posttest answers were as well thought through as my pre-test. (student L)
It couldn’t have been any longer than 10, 15 . . . I also read through everything. . . .

[The second posttest] went quicker than . . . the first time. (student J)

It took me a while . . . maybe 1 hour [for the pretest]. . . .20, 30 minutes for the
posttests. . . . I think 20 minutes [is the right amount of time for me to complete the
tests]. . . .I’m really slow at everything . . . maybe I just spend too much time on the
first few questions, and got to the end, I was like, “Uh-oh, I’m running out of time.”
So that last one I had to rush through a bit. . . . When you have so many choices, we
get to pick so many. . . it takes me longer than just four options and choose one . . . I
think about every one . . . this one’s more important than this one, this one’s similar
to this one, so I don’t want to pick them both . . . they take me a while to go through.
. . . Having more time is better. (student M)

Students expressed their understanding of systems thinking as follows. Student H
looked at the big-picture perspective of an agricultural operation and thought about all the
things that might be impacted. Rather than focusing on a certain disease to treat, a
veterinarian should consider a number of other things that might be managed. Student I
thought the focus should be more on recognizing all the factors that are flowing to the
individual animal, trying to get that whole picture, and addressing different factors that could
be playing into what’s going on. Student L considered backwards thinking in which one
thinks through the clinical science that’s presented to get to the disease rather than working
on the disease and expecting certain clinical science. She thought systems thinking is
working through the logic of how you approach a problem, and that a systems approach
would keep her focused. With her focus on performance indicators in the big picture, she
would be less likely to overlook something. Student J believed that, from a systems
approach point of view, one needs to know everything that might affect the situation: staffing, protocol, cow–calf management, milking–herd management, hand washing, sanitation of the environment, the vaccination status of cattle, infectious disease agents that may cause an infection, pasture, any type of parasiticides in use, where the milk is being used, where the milk end-product is going to go, who they are selling to, what the market is, and more of the basis behind the operation. To her, that approach made much more sense than rote memorization of “this agent causes that disease.” Student M thought the systems approach helps one see the big picture and how changing one thing may have a ripple effect down the line. Further, the systems approach helps by leading the veterinarian to take a step back and look at everything overall and not just focus on the details. The students’ specific comments were as follows:

It was a little different way of presenting it to go through especially the beef case; we had to kind of put a lot of different components together and do some detective work, so that was really interesting. . . . One of my favorite parts of the test [was] where we had to take several different pieces of information and then make a decision based on that . . . just to look at an operation from the big picture perspective and think about how all the things that are impacting that, not to get focused on an infectious disease or something that we might want to treat as a veterinarian but . . . a lot of other things that can be managed and we have to look out for those too. (Student H)

It’s an approach . . . to identify all the different environmental factors and genetic factors that could influence those animals, and then . . . you decide how you can . . . either improve their health or . . . the profitability of the operation or decrease disease incidence. . . . It’s not just farm cleanliness, it’s also . . . the genetics of their animals
and when they’re having babies and how those babies are moved around. So it’s a very complicated system, but the more factors that you can identify that influence the animals, the more effective you can be identifying problems and finding good solutions that can help them. There are all these factors in the environment that play into it, and if we don’t recognize and understand them we aren’t really understanding the process and the animal. The usefulness in trying to get the big picture and trying to make sure you’re addressing a lot of different factors that could be playing into what’s going on. Transportation is a big deal to a sow. What is their parity level? All those factors are playing into it. From the first time you step onto the farm, your focus is more on understanding all the factors that are flowing to the individual and trying to get that whole picture and understanding of what’s happening to affect the individual animal, and then looking at those different—I’m going to call them opportunities—but specific factors that either can be changed or not changed to affect the animal’s health. I like the thinking behind it and how it can be used in multiple applications. Like in theory you can use this on every farm whether it’s sheep or goats or cattle or swine or cats. You’re looking at all the environmental factors and seeing if places you can act to affect individual animal in a systems approach course versus the individual animal working in a beef records course. (Student I)

Systems thinking is working through the logic of how you approach a problem rather than learning about the diseases and the outcomes of the diseases [and] what you do with the information from there. I consider it backwards where you have to think through the clinical science that you’re presented with to get to the
disease rather than working on the disease and expecting certain clinical science. . . .

So I think the systems approach helps with that more forward thinking. . . . I’m taking
the small ruminant elective now, and understanding the production systems has
definitely helped with those, so you can narrow down the questions you’re asking
and, if they are more likely to be attributed to the production or disease process, or the
disease processes that have been at a certain stage of production . . . I get distracted
and get scattered. So having that systematically work through each thing keeps me
focused and I’m less likely to overlook something. . . . I like the algorithm—I think of
how to think through, teaching the logic of it. . . . It’s helpful when some of the
teachers test you. . . . The logic algorithm and the informatics part . . . you’re given a
whole bunch of information, and then you set it to equations to get to how your
performance levels are, performance indicators. . . . With the big picture, it helps with
reminders on what else I’m supposed to think about. . . . It helps when I can break it
down into smaller pieces. . . . It’s organized chaos. (Student L)

It’s a good way to analyze everything. But it’s so true in our production systems,
especially swine—you’re going to not just have one swine farm—you might have a
producer who has 10 different sites. And you need to look at each site objectively . . .
so it can help identify what’s that little bit different on every farm. . . . Dr. [R] gave
the example of the scouring pigs. It makes so much more sense to talk about it in a
systems analysis, that here are the agents that cause scours. You don’t know when
that’s going to have an outbreak . . . you do with the systems approach. . . . I’m a very
concrete . . . step-by-step . . . sequential type of person. . . . I linked on to [the
lectures’] learning styles a little bit better than some professors’ “come in and here’s a
PowerPoint, go go go go go.” I like to take a 10,000 foot view, 5,000, 2,000 right there at the ground. . . . I really like the four circle—I think that’s a good idea—and how altering an inflow affects your outflow. Something in the middle, a change in management, will affect your outflow, better or worse. . . . Systems thinking, especially for production medicine, would be my way of organizing and looking at a farm or a producer or a set of farms and saying, instead of looking at the current problem, for example, mastitis, to take a step back, and look at every aspect that goes into that production system. From staffing, protocol, cow–calf management, milking–herd management . . . hand washing, sanitation of the environment, the vaccination status of a cattle . . . infectious disease agents that may cause that infection . . . pasture, if they’re doing pasture, any type of parasiticides that they’re using, where they’re using milk, where their milk end-product is going to go, who are they selling to, what is the market . . . and more of the basis behind it. . . . E. coli can be shed from carriers and shed more from animals in stressed environments. If these are newly weaned calves, and they haven’t been vaccinated, and we just moved them to an environment near younger calves, then we probably have an E. coli situation. That makes sense from a systems approach, than just learning rote memorization things. . . . Looking at all the aspects and things that can play into the production of that product, or the health of the animal at the end of the day, but looking at it on a herd basis and a management basis, and here again, the input, and the inflow, and the outflows. How one change in one of those aspects can overall affect the end product and seeing how those all play in each other, they won’t all have equal importance or percentage values in affecting that product. . . . Anyway, I can make a farmer more
profitable and have a better quality of life, and anyway, I can make the animals healthier, feel better, have a better quality of life, that makes me happy, and this is a tool by which I can do that. . . . Systems approach would be much easier to learn, and more practical. . . . That’s why I like it so much—it makes sense. (Student J)

I have no large-animal experience at all. . . . When they . . . break it down into . . . systems it’s really helpful, because then you get to see the big picture . . . [and] a little management perspective also. . . . The tutorial definitely put everything . . . [into] a broader perspective. . . . It helps you take a step back and realize that you’re not just looking at each individual animal . . . [you] look at the whole picture and how changing one thing will have . . . a ripple effect down the line and everything. It definitely helps put everything together . . . things I’ve learned in other classes . . . thinking of everything as a whole, and not just looking at . . . the details . . . breaking it down into . . . concepts that are more understandable, and that kind of flow better. . . . Learn the details but . . . don’t focus on it initially. . . . Look at everything overall, so you understand what is going on and then you can go deeper into the details. . . . Anytime we have a case or situation we’re automatically thinking, okay, what different things could it be based on the age and environment and things like that, and then just try to narrow it down in our minds . . . and . . . go from there. It’s kind of preparing us for next year. . . . If we had that case, okay . . . start broad, this way you don’t forget anything and then . . . rule things out based on the situation. (Student M)

However, some students had the misunderstanding that systems thinking was only for macro systems, such as food production, but not for micro systems, such as individual small-animal biological systems, as illustrated by the following comments:
It’s a way of looking at animal health that tries to include management as well as traditional healthcare and think about the environment the animals are in and how what we do impacts that. . . . Thinking back to small-animal med last semester, that’s very individual animal oriented. . . . You just feel like you’re missing the big picture. . . . It’s also not as applicable though because you are doing medicine on an individual animal basis. (Student H)

I think it’s innately known for production-animal people. Small-animal people, I think, have no concept of it. . . . “Oh, here’s the dog that’s for its vaccination and had a cut in its paw and we fixed it up.” There’s not that production system thinking analysis that has to go on in their minds . . . but for them to hear [it] is especially good. They will one day have to go and work with our large-animal clients. (Student J)

When the Stella simulation model was introduced to apply systems thinking, student I was overwhelmed with the numbers and graphics, saying:

I get kind of overwhelmed with . . . the big graphs and . . . the printouts, and I don’t really understand, I’m not too good with that. . . .The topic is kind of intimidating to me when it’s presented like that because I don’t really like math and I don’t necessarily love things that go on graphs or modeling.

On the other hand, student L thought it was too time consuming to build a Stella model from scratch. She preferred to have a previously constructed model for students to work with, commenting:

I was actually paying more attention to the software program that he was using. . . . It was confusing when it was presented all at once, but that step-wise pattern that he
showed, I really appreciated that. . . . I was interested in it going back to the
informatics and how the different ratios and different equations that you use from the
information that you’re collecting reflect back on the disease processes that are
occurring. . . . It would be too time consuming to do [the Stella model], and it
wouldn’t be efficient if I were to do it myself, because I tend to get lost in the details.
. . . But I do like Stella, so if [there] was already a model there, and you were learning
how to evaluate your informatics based off that, I would be okay with that . . . but I
would like that ability, that would be very nice if the way I thought about it didn’t
quite mesh, if I could change it, just tweak it a little bit; that would probably make it
easier. (Student L)

Some students were not fully able to understand systems thinking. For example,
Students H and L were confused by the design of pre- and posttests. Student L thought it
would be helpful to discuss how each part of the lecture ties into the overall system. Student
I thought practicing different scenarios might help her better understand systems thinking.
Student K believed in hands-on exercises, experiencing real work such as in an internship,
and PowerPoint slides as a study source. She thought systems thinking was useful only as a
review at the end of the section. Student J would have liked to have the math behind the
systems models explained and to receive hands-on practice. These views are illustrated in
the following comments:

There were some things on the tests that I found confusing, like in the goat scenario it
has the questions, and then it gives the answers to the questions. So, I don’t know,
maybe that’s supposed to help me decide which questions are more important by
having the answers there, but as a veterinarian you don’t have the answers when you have the questions, so you just have to come up with questions. (Student H)

The more ways we can see it used, in different scenarios, the more applicable it becomes to being able to use it. (Student I)

It’s only useful at the end of the section, only as a review . . . . I don’t remember that (swine case) slide. . . . I’ve studied everything for the class, but [the instructor] didn’t give us that PowerPoint. . . . when he went through and talked about cases. . . . I don’t know if you’re talking about . . . going through a case systemically . . . through it step-wise, or . . . systems as in the reproductive system versus the respiratory system. . . . I don’t know what you mean by that term. . . . so, no, I couldn’t tell my friend what that meant. . . . Case-based learning for me is not very helpful without actually having to do the cases. . . . I’m not seeing the actual patient; I’m not interacting with the producer; it’s not very helpful. (Student K)

I got kind of confused at the beginning, because the test asked, “What questions would you initially ask the producer.” And then it gave you the answers to pretty much all the questions and then the questions you should have asked. And I was happy with the questions I should have asked, but it took me a while to figure out that was what you wanted . . . Dr. [P’s] . . . was more of an informal [12-minute] lecture . . . I don’t really remember. . . . If anything, it reiterated what I already knew. . . . I don’t like looking at [the Stella systems model] as an overall map, because it gets too busy and, with me, I scatter and I’m looking at everything at once, and it’s hard for me to adjust. . . . I liked it better like with Dr. [R’s] presentation when he went through step by step, and then seeing the overall picture. . . . Even after you see the
overall picture, I don’t like looking at it for too long. Because then my mind is being scattered and divided and not focused. . . . If they would break it down with each lecture and say, “This is a part of the system that we’re discussing today, how it ties into the overall system.” Yeah. That’s how I would have to learn . . . the most beneficial [way]. (Student L)

Explain a little more of the math behind it. . . . We don’t use [math] in our schooling, unless you’re making up a drug calculation, but with practice that can become quite a simple calculation. You’ve done it enough times, you know how to go from the mils of something and how many milligrams are in it, so what’s the final dose. That’s pretty straightforward and they do that, but that’s a really, truly small-animal thing. . . . You’re not going to be called out into the field, you’re not going to have a client come in large or small and say, “I want you to tell me all about how to culture E. coli and x, y, and z behind it, and the different samples.” . . . That’s something that we as veterinarians we need to know, but seriously, in my opinion, not to that depth that they teach, for example, in microbiology or infectious disease. Yes it’s important, but if we’re not sitting in the lab, if we’re sending the samples in—we have to know how to send them in so the lab can do their job. (Student J)

In order for them to thoroughly understand systems thinking, some students suggested starting to teach it earlier, such as whenever students start learning informatics in high school, during the first two years of undergraduate studies, or during the first year of Veterinary Medicine. Environmental classes in high school and science classes in college would have been a great place to introduce the concept. Other suggestions included breaking up the class and providing a tutorial just for people interested in large-animal study;
providing an overview on the first day of the class so everyone is on the same page and students are paying better attention; have more classes using the concepts throughout vet school; having concurrent courses such as shelter medicine, beef records, etc.; having an elective or online lecture specifically about systems thinking; allotting at least one hour of time per species for the four species’ categories; teaching in the conventional way at the end of a main topic; including more real-life examples, such as small animals, and working through them with many exercises; continuing systems thinking application and practice in the clinic, rotation, and internship, but not in the classroom; incorporating systems thinking with live animal study, including aquaculture or exotic zoo cases, to relate a scenario not covered in the curriculum; having instructors explain their thought processes and how they may have had to change their thinking; providing PowerPoint support for review; providing articles, a VIN [veterinary information network] thread, or a CE [continuing education] where people can talk about how a systems approach actually was beneficial; providing graphs for dealing with diagnostic questions in the scenarios; avoiding overpowering students with information; providing positive reinforcement; encouraging role play; and providing herd data and a Stella model template for playing with the numbers. The ideas are illustrated in the following comments:

Have more case examples instead of just showing a flow chart generally . . . [such as] a case that illustrated some of the systems thinking. . . . Dr. [R] was focused on an infectious disease problem, and then the answer was actually based on management or something related to the system. He could explain to us how he thought through the case and how he had to change his thinking . . . . [Tell students about all the cases he experienced, how he solved those]. . . . If you grew up on a farm, then you
probably would have the opportunity to be introduced to [systems approach] very early. If you’re not really interacting with agriculture until undergrad, like me, start . . . whenever you get into your major classes, so probably sophomore. . . . Undergrad is a good time because you get to think about or talk about things kind of in an abstract sense. . . . People are really open to new ideas and a new way of thinking about things. . . . Now in vet school we have to memorize set facts, and we are learning how to apply them, but our philosophy is kind of already formed—we have a certain way of approaching things. . . . It can be incorporated throughout the curriculum and referred back to within the different examples and material, but I think just to introduce the concept, [the amount of system thinking lectures] was good. . . . Because it’s a philosophical approach, it impacts everything we do as veterinarians, and I don’t really think it can be isolated into a separate subject matter. I think it’s something that should be applied to every case and every topic . . . [with] five minutes [systems thinking] per lecture. (student H)

I’ve taken beef records before, but he did not present it in a systems-based way. . . . I’m taking VDPAM 310, and we had a little bit of systems introduction in that class, kind of concurrently with the VDPAM 445 introduction. . . . The earlier introduction you have to them, the more you can apply it to those other classes that we’re already doing. . . . like the introduction on how it’s applied on farm and how people are using it, especially those cases that aren’t clear-cut where it turns out that . . . The transportation of something that’s affecting disease . . . you don’t get to that solution until you look at all the factors that are affecting these pigs. . . . That’s really what made it more clear to me . . . the fact that he talked about it in depth with . . . the
species specific... swine problem... Even if other people... are using other
species... you can tell me the physiology of renal failure but when you give me a
renal failure case, [for which] you’ve... the symptoms... [and the] sick cat
presented, and here’s the things we tried that didn’t work—that’s when I actually get
renal failure... That’s not always how our classes are presented, but to me that’s
when I really learn... That’s when I really understand the concept... doing a case
on our own... using it in a scenario or a case, and maybe having options of different
cases so you can pick something you’re more interested in... a shelter option, or...
a small animal—because there’s a lot of issues with shelters that related to this... We have a shelter medicine class [in first-year Veterinary Medicine]... it would be
good to use it there too because they talk about how we need to use herd concepts in
the shelter. I think they would be very open to refining that to be more constructive
and systems based, which... gives us... that framework to use it... at the shelter
and figure out what’s going on... That would be another good place to introduce it
because that’s really relevant in that situation... how we can use that to figure out...
how is the animal input, what are we doing with them, do they go to isolation or do
they go to quarantine, what if a disease happens, what kind of diseases, what’s
immunization?... Those are all the factors that systems can ID for us... We just
need it introduced... because it’s a lot of just medicine... individual animal
medicine, but if we had more... interspersed in the semester [that] would help for us
to be able to use it later... At least one hour time per species... We do sheep and
goats, we do swine, we do beef cattle, and then kind of like a ruminant general cattle,
so that’s at least four... Adding it into shelter med would be a really good idea...
There are people with nine cats, or 15 cats, and there are shelters that are going to need our help, and these things can help them if we aren’t intimidated by it, and if we can see it being applied in other ways. . . . There’s a lot of us that don’t really love production animals, that could see ourselves . . . consulting for a shelter. . . . That would be an awesome option to have for those of us that . . . don’t really think we’re going to deal with dairy cows. . . . I would hope that there would be . . . an article or like a VIN thread or something where people can talk about how [a systems approach is] actually being used and how it’s beneficial . . . some CE or place to go for. . . . veterinarians that are using it, or using pieces of it or adapting it. . . . [Systems thinking should be taught at Veterinary Medicine beginning in the] first year. . . . You have a lot of information that you’re synthesizing, and it’s all new anyway . . . . Everything at that point is new, and I think it would be good to introduce it there because it’s a framework . . . that you can use in other classes, and then clinically . . . an earlier introduction would be better because there’s a bunch of new stuff anyway and a new way of . . . solving problems or looking at farms or looking at populations. . . . One more new thing isn’t that big of a deal at that point. Now for me it seems very foreign, because you’ve spent all this time going individual animal, what’s its history, what’s its clinical science, then I go to diagnosis, then I go to treatment options, and I try treatment options and I reframe my diagnosis. So that’s three years of that formula. Whereas, this looks at outside factors onto the animal, and then we kind of pick and choose what we can kind of fix or not fix. You get to a similar goal, but it is a little bit different way of thinking about it. . . . The best time to introduce it is when you already have a subject that applies to it. . . . Beginning environmental
classes in high school and science classes in college . . . that would have been a great place to introduce it—where you’re already teaching a system that easily falls into it and gives examples on it . . . . This is something I’m learning and I understand, and this is how systems based thinking is applied to it . . . . I really think it needs to continue either to rotations or start earlier and have more classes with it because I don’t really feel like I could go on a farm necessarily and understand it enough to use it yet . . . . We need more practice with it . . . either more cases, or using it on a farm, or . . . actually having an example and using it . . . at least another semester worth, plus . . . applicable rotations . . . . Introducing it earlier as a way of controlling infectious disease in our small animals . . . or nutrition or the fact that they have all these different sources . . . makes it more relevant for those of us, because . . . three quarters of the class probably aren’t going on farms . . . . That doesn’t mean these concepts aren’t important . . . [but] we do need to present them in a way that people like me can get a hold of . . . . [By] presenting it in more species and examples . . . it’s easier to learn it . . . . I’ve had 3 years, 7 years really of learning it more like physiology-based and individual-mechanism-based and animal-based, and then I’ve had . . . 3 weeks of systems . . . . Systems is a good way, a good framework to work in, but . . . should be introduced earlier . . . . [Pre- and posttests] didn’t make more sense to me until [the instructor] did the lecture this week . . . . A full explanation of what systems is and how it’s applied . . . a specific problem, like gilts and scours . . . using a specific on-farm problem to explain how it’s used is really beneficial to me to understand it because [otherwise it’s] just like giving a broad overview of it. (student I)
It wouldn’t be helpful until at least middle school. . . . probably the first day of classes [at Veterinary Medicine] when you’re going to have peoples’ attention the most. . . . [You] really want to explain what that is and what you’re doing. . . . If they want to do systems thinking teaching, they need to incorporate live animals into it. . . . For instance, if you were on the dairy rotation and this is how they wanted to do things . . . the clinician set the scenarios up to you when a case comes in. Like, “Okay, this is the case, this is the background, what questions do we want to ask the producer, okay these are the questions we asked the producer, here are the answers, what are we thinking now?” . . . It might be helpful . . . if they actually had a lecture talking about that specifically. . . . We had the course last fall—I thought that seemed sufficient. . . . Otherwise it’s not helpful . . . you didn’t actually incorporate it really that much . . . and it was never explained to us exactly what’s happening . . . there wasn’t an explanation to begin with. . . . Dr. [P] did that at a time that was relatively close to an exam, and he told us we would not be tested on it, so I guarantee you about 75% of the class zoned out and stopped listening. . . . It’s not helpful for me if I’m not actually seeing the patient . . . the situation . . . talking to the producer. So we could talk about it in class, and maybe I’ll figure it out during class time, but I’m not going to retain it. I retain by doing. . . . [I practice systems thinking in the clinic but not in the class]. . . . Throughout this entire experience at Vet school, anything that I learned in practice, or in practices during vet school, I retained far better than whatever they talked at us about in class. . . . I don’t think this would be a good idea to incorporate into the education. . . . because . . . I learn by doing [it in rotation]. (student K)
Role play for the most part . . . helps you work on your own algorithm. . . and how you want to work through the problem. . . Until you do it, the message isn’t really related to you, because everybody customizes it to themselves. . . Dr. [R] did a scour case . . . with the Stella program. You have benchmark numbers for some variables, but not all of them. So, he touched on that, which was helpful, but I guess you have to be a certain specialty to really go into what benchmarks should be, and they change year from year. . . He says that you can change the numbers to see how it affects the overall outcome. It’s a good idea in theory, but I don’t think I would do that by myself, unless I had . . . herd data that would make me go, “Oh, the herd’s doing this,” so I change the numbers, and I can see the outcome. If I don’t have that structure of actual herd data, just playing with numbers, it doesn’t really mean anything to me, the outcome. . . It’s harder for me to make that association with what the numbers are really saying. . . Course-wise . . . I would break it down and focus on each aspect of the system and how it builds in. In terms of case examples, they didn’t quite get to those in their lectures; they just worked through a generic production system rather than applying [it and] . . . seeing the different scenarios. . . [It] might be helpful to include aquaculture, exotic zoo cases, because that’s forcing you to use more of the systems approach and its algorithms, because you don’t necessarily know those production systems, but you can still use what you’ve learned with the systems approach to apply it to that scenario. And it gets you out of your comfort zone, which I think is important. . . If you still apply that logic and that algorithm that you’re used to working with . . . you should be able to come up with an answer and be able to work from there once you get your answer. . . [You should]
get familiar with the production systems. . . . That way . . . you’re better able to relate diseases that occur along a timeline or occur along a production phase, because that helps you in your thought process on how to come up with a diagnosis, and gives you ideas on what you should be looking for. . . . It would be fine [having learned systems thinking] freshman year when I started with Animal Science. So that would be helpful, just, because we learn production systems, management systems is. . . . [It’s] a good way to put it, because you’re looking at it, it’s looking at numbers, it’s the informatics section, so whenever you start informatics I think it is appropriate. Vet school starting is fine as well. . . . I wouldn’t really have benefited from it in high school. . . . I’d like more on the informatics side . . . more application of systems. I understand the concept of system thinking just fine. It’s more the application . . . with organizing calving rates, pregnancy rates versus conception rates, and how those numbers intertwine, what you expect to get out of those numbers, which I think Stella helped with. I’m not sure if there are other programs that work with that. . . . I’m not comfortable with Excel or processing records for that matter. . . . One or two credit hours . . . once a week . . . [the entire semester, just learning the applications is good]. . . . With beef records, we work on some Excel spreadsheets, but I’m not necessarily comfortable making my own . . . and working through the numbers that way. . . . They have a section where you can work with herd data, and you might be applying more in that instance. . . . I’m kind of intrigued about the pork and the hazard ones, and which questions would have been the best ones to ask, because I wasn’t quite sure what information we were trying to get. And what I was trying to do as . . . the producer . . . the plant veterinarian, not necessarily a state veterinarian. I think that’s
where I was getting mixed up, because I was thinking more of a state regulatory veterinarian than a plant veterinarian. (student L)

This is . . . more applicable to production animal medicine . . . it’s so important . . .

We give it kind of right at the end, and I’d like to see more . . . Students need to hear more of it . . . whether in this class [or] incorporate it more into VDPAM 310. Have an elective class . . . Everyone should be exposed to it . . . as much as we possibly can. Give more examples, not . . . an entire lecture just on it, but if you have that subtle undertone. We know that Clostridium causes disease . . . [such as] rotavirus . . .

. . . Give it in an example . . . more, more, more . . . examples . . . At this point, as a VM3, other students are starting to get to the point we don’t want to do group projects together . . . But this is more fun . . . more practical, and students like that better . . .

In class have some time to . . . call on people. I think students would like that to a certain extent. Not too much. VM3s are kind of at the end of a rope . . . Dr. [R] . . . has his slides and he doesn’t overpower the information . . . Be blunt, get to the point: how does this apply, how can we use this in the field? . . . He’s much more verbal than reading verbatim off slides . . . He does a good job, Dr. [P] . . . Dr. [K] also does . . . Not everyone in that class wants to be a researcher. Not everyone wants to be a small-animal surgeon . . . We get so overwhelmed with the amount of information that’s on slides . . . A verbal presentation from a professor is much more applicable . . . Dr. [K] . . . showed the whole model, and everyone went, “Oh, that’s a lot of information.” Then he went . . . step by step by step. [That] was concrete, sequential . . . Especially if you have a visual, break it down . . . Dr. [K] did the same thing with his slides, and Dr. [R] with the four circles. They showed this image
of a barn with four circles on it. Then they went, “Here’s step one;” and gave an example, and told, “Here’s what you’re looking for . . . da da da da da.” . . . Give us the overall picture of the overall picture on a production farm, and then [go] step by step. I think that works really well. And [don’t overpower] us with too much information . . . I would like to see more scenarios in class. . . . It should be like that in other courses . . . more real life examples, images: “Well here’s an image of a lame sow. 30% of these sows are lame on this farm. We are culturing ‘this’ out of the wound.” Yeah, you can treat that, but that’s not fixing the issue. You’ve got to be proactive instead of reactive. . . . Giving those examples of situations like that . . . solidifies it better. It’s [the scenario] to the point. [Pre- and posttests were] not too long. . . . Any longer we would start to probably just click boxes. . . . We were able to finish it at the end of class yesterday and before. It’s not too much information. I like that you gave the graphs for the beef. That was good. Because it started to get a little too much information, but then here again, visual, you could see it. . . . VDPAM 310 . . . is more of a production mindset, but I think these principles can apply to anything: shelter medicine, even your small-animal clinic. . . . I think that this should be an elective. It should be its whole own thing. . . . It’s important to start as soon as you can. . . . A mom cooking in the kitchen . . . you don’t just grab all the ingredients and throw it in a bowl. No, you take step by step: “What do we want to make? Cookies? Okay. How many cookies do you want to make? So we’re going to need these ingredients. Well this is how much we’re going to need of each ingredient.” Now if they didn’t come out right, what went wrong? Did we include all the ingredients? Was the stove not warm enough? Was one of the ingredients expired?
Was it the pan? So I think it’s everywhere around us, it’s just how we choose to identify it or not. In terms of veterinary school, yeah [systems] should be taught all the way through. . . . They should start first year in our Case Studies, and/or Vet and Society. Case studies should involve it more. . . . It just looks at one animal, and one situation, one disease or one injury, and that’s it. They don’t give that overall picture and I think they should. . . . I think it should be bigger picture. It’s not just the cut leg. How did the cut leg happen? And they don’t say that—it’s more of, a horse ran into a fence. Why did the horse run into a fence? What kind of farm is it from? Is it a breeding stallion and he was freaking out because he has too many mares next to him? Or is a paddock full of young race horses? What’s happening? . . . I say double it at the maximum (8 hours). It would be maybe too much for small animal—have to be cognizant they are there. . . . for them . . . that might be too much. They don’t maybe care, or it will be a tool they can use, but it won’t be their major tool in their toolbox when they have to make decisions on a daily basis as a small-animal vet. It’s important but it’s more important for production. . . . It’s almost like a tease—you get a tinge of it, and [there are] those who really like it . . . and then it’s gone. And then we start fourth year. Is there actually going to be more presented? That would be good. Will it be presented earlier in our curriculum? That would also be good. You could even try . . . to incorporate similar examples into more of the small-animal shelter . . . if you want to keep more small-animal peoples’ attention. . . . Or how this would be applicable to a group of show dogs? . . . They’ll link systems analysis with production stuff, which they already link to being boring. They just don’t like it . . . but we have to keep their interest, and I think that’s especially pertinent. . . . You
almost have to trick them into learning about it because they see large animal and they go “[sigh] . . . We just eat them.” . . . They don’t think about food until they want to eat it. Until then, it’s someone else’s problem. They want to save the cats and dogs, and we need those, too. . . . But when the vast majority of people are mixed or small, it’s tough. . . . if there’s any way it could be incorporated to really catch those small-animal people more, I would support it. (student J)

Break the class up or do . . . a tutorial just for the people that know large-animal background . . . so you don’t have to bore the farmers in the class. . . . It’s also good that they have a refresher, and then they know right away to do it. . . . Some people come from a farm and they’re like, “All right, I know what I’m doing.” But it could be what they’ve done, but not what should be done or what . . . the professor would recommend. . . . Maybe give . . . a separate lecture or . . . an online lecture that they could watch, for people that have no experience. . . . This way they have . . . a little jumpstart into the whole thing. . . . [It depends] on what is going to be taught to each group. . . . If you’re giving . . . the Farm 101 basics . . . you might bore the large-animal people. . . . If you’re just going to start at the beginning, then it might be helpful to have everybody together. . . . The large-animal people can help out the small-animal people with no experience, and the no experience people can be like, “Hey, what does that mean? That means nothing to me.” . . . They can help each other out. . . . [For the] basic lecture . . . take the experienced people out and just focus on the people that have no experience. . . . [Add in] farm management . . . [when] going over the different types of pigs, different ages . . . different farm procedures. Like [for] management and swine. . . . or some other species that’s not
covered because it’s assumed that we know it, but I didn’t . . . I would definitely start
with a PowerPoint. I feel like having been through 3 years of Vet school and 6 years
of other college, that I’m kind of crippled by PowerPoints—that if I don’t have one I
can’t learn. . . . [Have] a little group discussion . . . afterwards to make sure everyone
understands. And then have some questions to go over, just to make sure everyone’s
. . . on the same page. . . . Dr. [P] had . . . [a] pretest on the first day of lecture. Just
kind of get an idea of what you’re getting yourself into. . . . It’s . . . a nice starting
point . . . everyone just got five points just for doing it. . . . Once you started learning,
then that stuff was graded for real. . . . For me, and then for other people that can base
their knowledge and know where they’re starting from . . . I liked how it wasn’t
graded per se. . . . This way I can . . . go by what I felt was the most important, not
have to worry about what someone else thought was the most important. . . . I was
able to think through and not have to be pressured by, “Oh, I have two minutes to
finish this, and this is so many points,” and whatnot. I just sit there and like, “Hey, let
me think of the situation, let me think what I would do,” and take a step back and
look at it in general without the pressure of points on it. . . . Dr. [R] gave everybody
the swine basics pretty much because very few people have a swine background. . . .
He gave an overview of everything and then broke it down . . . more and more, once
we get like the bigger concept. . . . So he was able to start everyone on the same page
. . . same starting point. . . . Now we’re going to go deeper . . . just starting broad. . . .
Dr. [R] puts it in a big picture, and I’m like, “Oh . . . one day if I decide to be a swine
practitioner, I have some starting point. I kind of know what to do” . . . which was
nice. . . . For beef and dairy . . . I feel everyone knows it, whereas not everyone does. .
I have no beef or dairy background . . . no large-animal experience. I feel a lot of professors just start right in, like, “This is what you do, everybody knows it, right?” . . . No, I’ve never milked a cow before. I don’t know this . . . Just having a little bit of introduction, or even having just . . . an elective class first year of Farm 101 basics . . . farm management, biosecurity, nutrition . . . I really would have appreciated that . . . Even in nutrition there’s . . . grains and forage and roughage. I still don’t know the difference to be honest. People just assume that everyone knows, and I don’t know what that is . . . Even if it’s . . . not worth any credit but just a way to get everyone on the same page, I think that would have been very helpful for me . . . I would have been able to jump right into Dr. [P’s] discussions . . . [and have] a more basic understanding and background to start with . . . Third year [at Veterinary Medicine is the best timing to learn system thinking] . . . because we’ve learned everything . . . had the background, and now we’re able to apply it . . . how we want, how we need to . . . [to] put everything together before fourth year . . . I’m not so sure how that would work in . . . very detailed classes like pathology and micro or just basically spitting out information . . . It would be helpful maybe junior high to high school . . . Their brains are more developed, but they’re into learning more complex things . . . [It] just provides a different way of learning it, not just like the straight memorization . . . A lot of it in high school wasn’t always just memorizing, but kind of integrating everything . . . You have the most time in class, and you have the most . . . instructor time with you. You’re in a class all day, and then you do homework and then go back . . . Once you get into college, you’re only in school for a few hours, and then you have a job . . . You don’t have that one-on-one time pretty much . . .
school . . . stuff just got pounded into your heads. They made sure you learned it. Because they weren’t as rushed as . . . college curriculums are. . . . This way they’re prepared for college. . . . A quarter to a third of the semester [is better for system intervention] . . . because this way it’s not just one lecture that you . . . breeze by and forget about. More repetition is obviously better. Actually with the volume of information that we get, whatever we don’t have to use right away, I know I’m going to forget it. . . . The repetition definitely helps. . . . Having it more and more will definitely help me understand it better and help me retain it longer and use it. . . . They should teach the basics first and . . . have us learn all the details and everything, and then . . . apply with the systems thinking and put everything together. . . . You understand the details that you’ve learned . . . have some idea of . . . not what’s going on but . . . what you’re doing, and you can integrate everything. . . . [For the pre- and posttests], I needed to keep going back . . . because I kept losing count. . . . If there’s a way to . . . tell you how many you have chosen already. . . . 5 or 10 . . . is fine, because it’s not all just about . . . the one right answer, which is . . . what we had been geared to do. . . . “What would you do if you were in this situation?” . . . You technically have all those options in your head, but which would be the most feasible, cost . . . you know most economical thing to do at that moment, and helps you think. . . . [In vet school . . . all our exams are pretty much multiple choice. . . . But this one actually lets you sit down and think, “Okay if I had this situation what would I do?” . . . I have all these options in my head. . . . It lets you think . . . helps you start a diagnostic plan. . . . You just get bogged down with too many details. . . . even . . . the large-animal medicine. . . . It helps put people on the same page and . . . starting point . . . [of]
what’s going on. . . . It also gives people . . . a chance to think about it better and to put themselves in their future situations. . . . It helps people in different ways. . . . I’ve never been able to read and . . . have it sink in immediately. . . . Reading assignments definitely help if they . . . go over it afterwards. . . . I still think they should teach it in the conventional way . . . at the end of a main topic, kind of go through the systems thinking, and tie everything together. . . . This way they weren’t just spending two weeks spewing out details. We can actually . . . put it together. . . . Now everyone gets it . . . use this, not just memorize . . . a bunch of random details that mean nothing to me. (student M)

To increase interaction for the intervention, some students suggested talking to the professor first; using devices such as clickers or online applications, such as a RW poll at the beginning of the semester; grouping up to respond to the instructor’s questions with incentives; teaming up to discuss a scenario and present the solution in the class; following the instructors out to a farm on a job or a feedlot operation during the fourth year rotation; talking to a client one-on-one, seeing day-to-day problems, and discussing all the different components that a veterinarian has to consider as part of the system. These ideas are illustrated in the following student comments:

Some of the diagrams that we had, like flow charts . . . was not a great learning experience for me to watch it on the screen. . . . It would have been better if it had been more interactive. . . . I’d had to come up with the solutions, but it was good to see something visual, so we could . . . see how each decision impacted the animals. . . . It would have been good in class if . . . the flow chart had . . . appeared step by step. . . . We get to a point where it’s . . . two arrows and Dr. [R] says, “Okay, what
are the things that affect the susceptibility of the swine,” and then someone from the class has to respond before we actually see that on the screen. . . . Utilize small groups in class and have people interact. . . . That’s tricky because . . . as a student, if someone gives me something to do in class with a group, I’m not always very excited because it means I have to think and I have to talk. So you would have to have points or a reward associated with that so students came to class and worked. . . . A scenario like in the quiz could be really helpful, but you’d have to have a goal of the exercise, like a certain decision or certain questions to choose . . . that the group would have to work on together in class, and then you’d have them present it to the other groups. So then they have accountability, they have to make the decisions . . . interact with each other . . . have a product at the end to work for. . . . My ideal way would be to follow [the instructors] on the job, which we get to do during the fourth year. . . . If I could pick any way to learn from somebody, it would be to go with them out to the farm, talk to a client one on one, see the problems they’re dealing with day to day and all the different components that a veterinarian has to consider as part of the system.

(student H)

I would hope that it’s continued during fourth year rotations . . . like [with] one of the clinicians . . . going on a rotation . . . beef or swine or sheep or goat. . . . [The clinicians] would try to . . . present the farm in a . . . systems way. . . . We might talk about foot trimming. . . . Look at the farm . . . talk about where are animals coming from . . . genetics-wise . . . reproduction, how they’re moving animals through the farm, their production needs, so that we can . . . continue those concepts but continue them on farm. . . . [Or] go to a feedlot operation; then we can talk about putting . . .
the feedlot in those . . . systems parameters to understand . . . what factors are influencing them, so we’re not just talking about respiratory pulse, but . . . how we can look at it in a bigger overall way to try to help them be more efficient, increase . . . productivity, decrease losses. . . . It’s very multifactorial. . . . Hopefully we can put it in this framework to better . . . ID what the problems are and then try to fix them—or realize that it’s not a problem we can fix. . . . That’s also . . . what systems can help you figure out: the stuff that’s either going to get better on its own or it’s just inherent. (student I)

Incorporate RW poll[s], so like the clickers, [electronically]. (student K)

Through rotations, working through cases . . . instead of the mentors guiding us and showing us how to work through an algorithm, it’s me as a student working through it by myself and then showing them and they can say, “Oh, did you remember to think about this part of the system or this part?” or “Why did you do this first? . . . This is how I would do it.” Learning through mistakes is probably the next step—supervised mistakes. . . . I think it’s . . . hard to do it in an equine setting, unless you’re thinking about body systems. (student L)

My starting point would be go talk to the professor first. . . . I went right up to Dr. [H] before any of this. If I hadn’t, I would still do the same thing—how do I get more into it? . . . He had mentioned that to me . . . [that] somebody has to go be the liaison between your big picture . . . everything you know. . . . the math and everything behind it, and people who do all that and go take it to the farmer. . . . I like talking, and I like working with farmers and the hired men. . . . Because I just so love taking complex ideas and breaking it down, that teacher aspect: “Well, hey Farmer Joe, this is what’s
happening. Let’s talk about it,” sit down in their house, and go tink tink tink. I enjoy that. . . . I want to help the farmer be profitable because I know what it’s like to be from a farm. If you don’t make money on your milk, or beef, or hogs, you’re not going to have a farm any time soon. (student J)

We have the RW poll . . . our computers. We click in and it goes onto the screen . . . onto the instructor’s computer, and you can see the distribution of everybody. . . . So you’re not singling someone out, but you can kind of get a feel of everybody as a whole. The class pretty much knows what’s going on. . . . I wish some professors would use [the RW poll] more as . . . “Okay, is everyone following what I’m saying? . . . Does this make sense?” But a lot of times . . . [it’s] for attendance. They’re like, “Okay we don’t care what your answer is, we just want to make sure you’re here,” where for some classes it’s for points, for a quiz . . . group discussions. . . . However, the person I sit next to is a large-animal person. I’m like, “What is this?” and, “Shh.” . . . Separat[ing] the class into groups is so hard because there’s so many people, unless we had . . . groups to start out with in the beginning of the semester [so] that when you get to class you sat in that area to kind of avoid the shuffle. . . . [The instructor] talk[s] to us and have people shout out answers, which does help a little because it’s not just straight lectures. . . . It gives you a chance to think, and somebody else will answer. (student M)

Some students believed that, in some ways, systems thinking would benefit students with a different focus. For instance:

Even small-animal veterinarians can benefit from it. . . . Although . . . that applies on a big farm level, there are probably situations where it is applicable on other things.
. . . I can see how it can apply even on an individual animal basis, because . . . disease . . . has disease characteristics. (student I)

This shouldn’t just be a production animal mindset. . . . These principles can still apply to small animal, especially shelter. . . . Whether it’s a big animal or little animal, it’s herd health. . . . The small-animals should hear it more. . . . It helps solidify those students . . . who are already on the track. (student J)

*Transferring systems thinking.* Student I expressed how she was not sure how to approach a problem using systems thinking:

Can I really use this on farm in a reliable way? . . . I don’t know . . . This might be ideal . . . How can we actually synthesize it to making it work? . . . [It’s] hard to understand . . . how that really fits in, because . . . you were identifying factors that you should look at . . . It just took me a while to get the connection . . .

Most students (H, J, K, L, and M) applied previous knowledge to do the pre- and posttests. Student H also used an elimination technique because she did not know what the systems diagnostic questions were. Student K thought it was necessary to know all the terminology before working through the problems. Student M applied basic medical and research knowledge to the problem, then added in the particular species. Students’ comments about this aspect were as follows:

I was definitely drawing on things that I learned throughout vet school, while I was taking the test . . . For instance I’m in an elective right now, which is small ruminant medicine . . . Some of the stuff in the goat scenario was applicable to that . . . process of elimination sometimes . . . I don’t necessarily know what the best question is, but I can eliminate some that I think are the bad questions . . . and then choose what’s left.
The test probably wasn’t the best method for me to learn because I didn’t have necessarily something that directly taught me how to choose the answer. (student H) All the questions seemed pertinent. . . . When doing the exercise, it was just, which ones did I like better than others . . . based on some of the other things we’ve talked about in other classes all around . . . through Vet Med—which am I going to be more concerned about. I did a field trip last year to a slaughter plant, so I guess keeping in mind some of the things we talked about there . . . our didactic learning that we do now . . . is more helpful . . . because I have to learn the base knowledge first, and I don’t think it’s helpful going through cases if I don’t know what’s going on. (student K)

I relied more on my hazard training for the swine. And I’ve had lectures on swine which I felt prepared for with that question. . . . Both of their lectures were of summary lectures of an overall system. (student L)

Some of the concepts didn’t really come to me until this semester or last semester in terms of having heard certain words or knowing certain infectious diseases. . . . But the cattle, I think my background was there. (student J)

Basically, pretty much what was covered, what they taught us, what I felt was most important, and whatever small-animal knowledge I could . . . relate to . . . general medicine knowledge . . . ignoring the species, but just trying to take a step back. . . . What’s the difference between everything and why are they separated into different pastures? . . . Apply . . . basic medical and research knowledge to it . . . then . . . add the species in. (student M)
However, most students were able to provide examples and describe how to apply systems thinking in different situations on a regular basis, as shown by their comments:

In swine, we talk a lot . . . [about] respiratory disease. . . . As a veterinarian, our first instinct might be to think about them getting exposed to a pathogen, but we learn that it’s also important to think about the stress that’s on the animals. . . . They’re exposed; they may not develop disease. So things like crowding and good ventilation in the swine herd could make them more susceptible to the pathogens. . . . [Stress] suppresses your immune system, and you could have the same dose of pathogen in a stressed animal versus a nonstressed, and the stressed animal would get [sicker] because they’re less able to defend themselves. . . . [Stress was mentioned in] immunology, microbiology, pathology, small-animal medicine, large-animal medicine. (student H)

I had a client come in . . . brought one cat to us. . . . They didn’t really want to tell us . . . they had 11 cats in the home. . . . They had just gotten this cat. . . . They wanted to know if this cat . . . could be a risk to their other cats [by] bringing in some diseases. Well if we would have just looked at this one cat, sure I could have vaccinated it and sent it home. But the reality is, they actually had . . . a herd of cats at home, and whether we think it’s positive or negative, this is what they have and this is what they’re dealing with, and they’re actually very concerned about the health of these cats. . . . What’s going on in that situation? . . . Are the cats indoors or outdoors? . . . In their case, two of the cats were outdoors, but the rest were indoors. And they didn’t know that if they kept them all indoors, they could have a much healthier population with a lot fewer problems than allowing just these two in and out. So
there’s a lot of things on how they were even keeping their cats, because it was a large population. I can help them to decrease disease and problems and costs, [which is] somewhat related to how they deal with problems on farms. People don’t think that people are going to have more than one or two animals, but the truth is it can be a lot and people are going to do it regardless. If we can help educate them in a way that’s not judgmental, but is things they can actually do at home, like, “Hey keep those two cats inside, maybe we get everyone tested for XYZ diseases, vaccinate the ones that are most at-risk.” Those are the kind of principles we apply on farm, but I can apply it to this house or this population or this shelter, and have a similar positive impact. They brought us one cat, but the problem was really not “Oh, what’s going on with one cat”; the problem was they wanted help managing their cat population. The way they were coming to us for help was just to bring this one cat in for vaccines. But in reality the problem wasn’t the one cat with vaccines, it was them trying to manage their eight cats they had, with the potential that they could be bringing more in. They didn’t know every time they bring a cat in, they’ve got all these cats we’re exposing them to disease. What we need to do is if you’re going to bring one in you need to isolate it, you need to bring it in to us, we need to test it and vaccinate it, then we introduce it to the rest of the house. Well that’s a herd. That’s just what we do with our swine, or our cows. Same practices. And they didn’t know that, and that’s how we can help them. Specifically for ectoparasites, there’s topical flea and ticks that we can recommend to owners. Our bigger concern for them in their particular household was diseases like FIV and FELV, which are the immune diseases that are spread between
cats, especially . . . when they fight. So for them to allow two male cats in and out, and to have the rest of their cats be inside with a stable population, that was really high risk of those two male cats bringing diseases into the rest of their home cats even though those cats never went outside. . . . So, yeah, there are ectoparasite risks—those are something that’s actually pretty easy for us to help them with—but the disease transfer risks, that’s a much harder issue. . . . And it’s very hard for a cat that spent several years outside to completely have it inside and vice versa; a completely inside cat doesn’t want to go outside. (student I)

You get your call, and the producer says, “Oh I have this problem,” but you need to step back and look at the environment and slowly build your way towards the problem to make sure. . . . The producer’s going to be more focused on the problem, but he might miss outside factors that are influencing the problem. . . . It helps just to remind you to be more systematic—well that goes back to systems approach—but to address your problem systematically and consistently each time, so it’s seen as performing a physical exam. You develop your own system so you don’t miss anything. And you try to be consistent, and through that consistency you build towards narrowing down your focus. (student L)

We’ve definitely been exposed to it . . . goat . . . cattle . . . chemical . . . environmental toxicant . . . toxicology . . . Those principles still can hold the same. . . . You can extrapolate and say, “Here’s a beef scenario, here’s a goat scenario,” and you know that there’s going to be infectious diseases, but there’s also going to be managerial. . . . [Do] you vaccinate prefarrowing or prebreeding? And a pig . . . they’re only going to be pregnant for a little over 3 months. In a cow . . . they’re
pregnant... 9 months. So things change just a little bit, not too much... “Oh, hey Dr. [H], we’re having an issue with our somatic cell count. Can you come out and look at our farm [in the next] couple days when you get a chance?” And not just look at, “Oh, what’s the infectious agent?” and do a somatic cell count—what is the hand-washing routine of your employees who are milking? What are the shape of the milk inflations inside the claws that you’re actually milking with? How clean are the pens? Where’s your pen? How close are the calves that are 2 weeks and 6 months of age? So I’m very into that, and I would like to learn more of the consultant mindset. (student J)

*Concerns of learning and teaching systems thinking.* Despite the special assessment design, students were doubtful about the usefulness of systems thinking, as illustrated in the comments below:

My frustration with it is I... wonder... how useful these models are in a real-world situation. . . . I really don’t know if you’re going on five farm calls you know, a day; are you going home and being like, “Let me address this on a model basis”—do you know what I mean? . . . I just don’t know if you’re a mixed animal practitioner, or something that’s not really exclusive to swine or poultry or one production system, if you’re seeing a lot of different farms and animals and have a bunch of mixed cases . . . how much can you really bring this into your everyday practice? (student I)

I think that we get the kind of knowledge to do what I assume is their ultimate goal of being able to. . . . No, I don’t think it would be helpful at all if our classes were taught like that. (student K)
Students were concerned that something was missing in the Veterinary Medicine curriculum. For example, they believed that beef records should have more of a systems-approach structure. The current lectures in general at Veterinary Medicine helped students learn a portion of each system at a time, following which a professor may or may not tie the material together as a whole in a conclusion lecture. The students believed that some courses have tried to teach diagnostics, but they really don’t accomplish this; they just give it that name. A lot of professors delved into so many random, tiny details assuming that everybody had the same background. It was hard to consolidate the material, because just memorizing information they can’t use makes no sense. An elective class incorporating mathematics used in systems thinking might be helpful. The students’ comments were as follows:

[Systems thinking is] part of the curriculum that’s not included. (student H)

In beef records we had very similar scenarios that we worked through, but we didn’t put it in the confines of systems thinking. Although it was very similar cases and situations that we worked through . . . it wasn’t put in a structure. . . . It’s really a different way of approaching the whole farm . . . starting with sick animals and trying to decide how you can fix them or not fix them. (student I)

We already do that sort of with our Case Studies class. . . . That was helpful when we did it in there because that was the whole point of that class. But the emphasis wasn’t as much on solving the case as it was on going through the right process to get to an answer. (student K)

With the lectures (at Vet Med in general) right now, you learn a piece of each system at a time, and then the professor may or may not tie it in as a whole, as . . . a conclusion lecture. . . . There are times where you have those ah-ha moments later . . .
with a standard lecture. . . . “Oh, that’s how it fits.” . . . It might be helpful to have standard lectures just touch on that overall systems approach as a structure throughout the course. Or if we only had a couple of the systems lectures . . . teach an entire system, or if they would break it down with each lecture and say, “This is a part of the system that we’re discussing today, how it ties into the overall system.” Yeah, that’s how I would have to learn. That would be the most beneficial. (student L)

We do [diagnosis] in Immunohisto Chemistry . . . [and in other courses] just to rote-memorize the diagnostic test. . . . It’s a waste of brain space. . . . How about identify where the disease is probably coming from? . . . I tracked respiratory, vaginal discharge, any number of things. That’s more important to me. . . . The systems approach emphasizes that. . . . Where is the agent coming from? There are different tests. You suspect it’s what?—which this course and others have taught us: What do you suspect it is? Other courses have tried to teach diagnostics, but they don’t; they just name it. . . . I can’t change the curriculum; I’m not the dean. . . . An issue in some of our courses . . . [is that] people really want it to be nit-picky facts. . . . All throughout vet school they really don’t have us use [math]; I think that would be a drawback. . . . This [systems course] could be another course or an elective or production animal. . . . Mathematical teaching should be incorporated into it. . . . It’s important to know, “Hey, if I change this, this is what’s happening to our equation, and here’s why.” . . . If you’re going to do systems analysis, you’re going to be using a program to think. It would be good idea for production animal medicine or a veterinarian or consultant veterinarian to have a concept of the math behind it. . . . We have a mixed bag of students. Some are food-animal, some aren’t at all; some have
no concept of this, others do; some have great math skills, others not so good. So that could be an issue. (student J)

We . . . have concurrently Infectious Disease, which basically just does large-animal diseases. . . . I’m completely lost in that class because he goes down into so many tiny details like other professors. It’s basically where diseases start from. And he’s just assuming that everybody has a background. . . . A lot of large-animal stuff is management, and I’ve never been on a farm or anything. . . . I don’t know what you’re talking about. . . . I can’t put it together; it makes no sense. I’m just memorizing stuff that I can’t use. . . . I know for other classes I just memorized details and then walked away from that class going, “I don’t know what happened.” . . . I didn’t learn anything; I just learned all these random details that I’ll never use. . . . All the bigger picture things I didn’t memorize or I didn’t learn because I was so busy focused on the little stuff that was on the test—not the big picture stuff that I need. (student M)

**Instructor’s interview.** The interview with the instructor was guided by the six general questions shown in Table 4.9. This discussion of the interview is organized into three major sections: need for faculty training, challenges of implementing systems thinking in classes, and need for improvements in teaching with a systems approach.

*The need for faculty training.* The discussion of the need for faculty training is based primarily on the instructor’s interview responses to three items (see Table 4.9): (a) materials that would be helpful for faculty to learn the concept of systems thinking (interview question 1), (b) practices to help faculty better demonstrate the systems approach in class (interview question 2), and (c) did you ever learn systems thinking or similar form before Dr. [H]’s
training sessions? (interview question 5). The instructor was concerned about the frequency and content of systems-thinking training. He thought all faculty at Veterinary Medicine should get trained each semester or at least annually with a 1-hour overview and 2–3 hours of multiple examples. The content should focus on each skill of systems thinking to develop 2–3 scenarios. He believed scenario diversity could help students and faculty to sense, see the pattern, link, connect, incorporate, and apply systems thinking in Veterinary Medicine. In addition, having Stella application experts in the group to assist building a model would be a plus. His thoughts are reflected in the following comments:

It might be helpful if all Vet Med faculty were trained for multiple hours on the details of each systems-thinking skills because the concept of systems thinking is broad and hard to stay up with without training.

I know Scott has a lot of mentors; they did some training ahead of time. . . . I was disappointed we didn’t get involved in [it]. . . . We thought we were going to be part of that, and especially . . . we were the ones who ended up having to develop the questions, but we didn’t have that training . . . and it seems like it was just a small group that got trained.

Training each semester or each year might help faculty to refresh their systems thinking since they may not use it for a year until the next time they need to teach. Last time it was easier for me to give this talk because it was very fresh . . . we had worked extensively. A year later, I hadn’t worked with the model . . . so I probably spent a good hour going through the model . . . just refreshing myself on how it all worked.
A little better understanding for the eight systems-thinking skills with good examples related to the scenario is necessary because it is hard to see the link, even for the trained faculty who grasped the concept.

Some of those examples that came up, I still struggled to see that link . . . a little bit more of the details sometimes that become a little bit more challenging. . . . And I think part of it is because . . . we’re a lot more ignorant on the topic.

To improve the scenarios, the instructor suggested developing scenarios that targeted specific systems-thinking skills and were more applicable to Veterinary Medicine:

If we know what we’re trying to target . . . a particular [system thinking skill] . . . that can be helpful.

It would be helpful to see examples that can be related to Vet Med, and representing each of the eight systems-thinking skills that are more strongly or more easily applied to Vet Med.

The tree farm example in the initial training was good . . . because that’s an area that we had enough understanding that we could see it work. . . . Following that up with a good veterinary example would be great.

I’m sure some of [the eight systems-thinking skills] again might barely apply . . . because of the differences, and some are more strongly or more easily, but those type of examples I thought were very helpful in seeing the process.

The training should include at least a 1-hour session of overview, with 2 to 3 more hours showing 2 to 3 examples.

If [the eight systems thinking skills] all fully apply, then I say, yes, each [systems thinking skill needs] a good thorough review of that [for an hour] and only that
[applicable systems thinking skills] would be very helpful. But there’s some that is kinda hard to connect to veterinary medicine just because of the difference. . . .

Maybe [use a] half an hour . . . [to] put together two or three [systems thinking skills] that are just rarely used in veterinary medicine in one session.

A whole hour dealing with multiple examples is better than one very thorough example because it allows us to see the pattern and sense how systems-thinking skills were applied to each case. A comparison of a familiar engineering example and a veterinary medicine example would be helpful to incorporate and see the total picture.

If we could come up with more than one example, sometimes that helps because, with a single example sometimes we’re thinking it’s different . . . If we start seeing two or three then it’s easier for us to see.

Maybe one good example of engineering that we could all link to, and then an example in veterinary medicine. That might help us compare, and then you know the engineering example would be something that maybe we’re a little bit familiar with, not highly technical but just a bigger picture. . . . Some of us . . . were kind of learning at the same time. . . . Sometimes we spend two hours on the big picture, but that’s too much time on the big picture. . . . We need one hour; just, “Here’s the big picture and then here’s the more specifics [for] each of the eight.”

[A scenario] that doesn’t require outside knowledge, like the tree, that was easy because you really didn’t have to have that outside knowledge. Once they told you a little bit of the process, I’m like “Oh, that makes sense.” But if you’re dealing with . . . biological that you have to understand all of these outside factors, if you don’t have that background, you could lose it very, very easy.
With pigs, if you understand it because you work with pigs, it all makes sense and “Yes, I get it.” But if I don’t know pigs, I don’t get it; where if I see a pig, a cattle, a food safety, you know, if I see multiple things; I’m like “Oh, I’m seeing the pattern now.”

Having a Stella expert in the group training would be helpful. It would take about 1 hour to describe the big picture of the Stella application and at least 5 hours to be thorough and double-check all inputs are correct without even designing. The tutorial created by the Stella expert helped.

Having someone who’s an expert in the [Stella] software . . . we could brainstorm, and then [the expert] made the software to map it out, and then review it with me, and then say, “Well, here we changed this,” so that made it a lot easier for me to be creative than having to learn the software.

If I had to learn the software, that slows down my process. . . . I may use it once every two years . . . with updates and all that, so just not enough time for me to focus and spend two hours or three hours and really get to know it fully.

It probably would take me one hour to just get a big picture. . . . To be thorough and . . . really double-check the inputs the Stella expert did was correct without even designing. . . probably would take me five hours. . . . As we had variables, I made a change, and then I watched my variables change, and as long as they make sense to what I expected, then I assume the calculations were right.

Ready for me to put my seal of approval, I would take quite some time to make sure that all those inputs. . . . But I didn’t try to follow the calculations or make sure that it wasn’t counted twice, or, and I think in this case it was easy because we were just
trying to give a perspective. I think if we really had values from research that we knew that this was—had this much impact—that would take a long time to just double check that it’s accounting for that properly.

The challenges of implementing systems thinking. The discussion of the challenges of implementing systems thinking in classes is based primarily on the instructor’s responses to interview question 3 (Table 4.9), which asked about suggestions for creating scenarios, the diagnostic questions, and assessing students. The instructor believed that there were several challenges for implementing systems thinking. These challenges are briefly summarized as follows: (a) Neither the instructor nor the experts could classify a diagnostic question as either a systems or non-systems question; thus, there were grey areas in the process, such as direct and indirect relationships; (b) the instructor had to spend precious class time getting all the students in this big class on the same page (i.e., providing swine background for students not on the swine track)—the background must first be established; (c) the instructor tried to achieve a balance integrating systems thinking into the curriculum both for the purpose of passing the course and the North American Veterinary Licensing Examination (NAVLE), as well as for success in practice, but NAVLE standards did not require systems thinking; thus it would time consuming to incorporate systems thinking into the NAVLE-based curriculum more permanently; (d) the College of Veterinary Medicine did not provide caseloads; they had clinicians, residents, who were required to get a case load, and senior students—that was the hierarchy. The residents were more likely to get the hands-on experience, because they had to perform hands-on work for their certification, but the students would simply observe. If they were just observing, how much were they really learning in about small-animal practice?
First, as mentioned above, neither the instructor nor the experts could classify a diagnostic question as either a systems or non-systems question, and there are grey areas in the process, such as direct and indirect relationships. The instructor could not classify diagnostic questions because there were no clear-cut yes or no answers. The process allowed limited interpretations such as how directly or indirectly the diagnostic questions affect one another. A question directly related to a systems approach was obvious, whereas an indirect relation, such as “maybe” or “kind of” or “not huge,” was not. Questions both directly and indirectly related to systems approach should be considered as systems diagnostic questions. However, either the swine experts didn’t understand systems thinking, or the processes and relationships were too complicated so the experts would just leave it. The instructor commented:

I don’t know which one it is: if it’s just that we don’t know it well enough to know for sure or if it is in fact just a kind of a grey area where yes it could be [as systems question].

It becomes harder because, as you’re trying to understand, it’s not easy to say yes or no—there’s a lot of maybes, and because of that then we kind of lose a little bit of faith because we’re so used to either it is or it isn’t. And if there’s a lot of maybes, then . . . we’re just not sure. . . . it depends on what your goals are, and it depends on the situation.

We argue many times, because the obvious ones are easy . . . we know have a direct impact. We don’t know how to classify those as directly a system or indirectly.
We implement it indirectly. . . . Coming up with these scenarios is hard . . . because we’re being forced to . . . address it directly . . . but I think that’s probably just because we’re a little bit ignorant.

The instructor had learned systems thinking the hard way:

When you go into practice, it’s that bigger picture that many times you’re trying to figure out. . . . That’s when you start learning: What are those critical questions when there’s a problem? What are those critical questions that I need to ask, that are pertinent?

If [the students] pick the correct system questions, what we can say we have achieved is we’ve got them to think of the problem differently from a different perspective. They might not be experts in system thinking, or fully understand it, but I think we’ve achieved the goal to get them to think away from just the agent, and more thinking the broader picture of impact.

Depends on what your objective. . . . System questions may be more important than non-system questions. . . . For example, if we have scouring problems, finding out that [it is] E. coli is very important from an intervention standpoint because that will be affected by some of our treatment. But from an overall systems thinking, that is not a system question. But because it is E. coli, that has an effect on it. So as a veterinarian, I can’t just apply the systems and not figure out what disease is ultimately affecting the pigs. I need to know what the disease is first, and once I know what the disease is, first, then I know the impact.

[For] another situation . . . Clostridium difficile scours, there’s no collateral protection; therefore, it doesn’t matter whether you’re from a gilt or a sow,
susceptibility is going to be the same. And because of that, we eliminate that whole gilt issue, we eliminate that sow issue, which means . . . then the whole issue of replacement . . . is irrelevant . . . replacement rate does not play a single role in that. . . . What makes it complex is, it doesn’t always apply.

The instructor believed that systems thinking is more for macro systems rather than micro systems—for a large-animal populations and not for individual small animals. He commented: “A lot of the students are trained to identify the individual animal. And when you’re dealing with the individual animal, systems thinking does not apply. It only applies when you’re thinking of a population.”

The second challenge was that it takes time to explain the systems approach to students in a bigger class because they need enough background to see the big picture, especially when the only scenario embedded in the class is not in their chosen area. An instructor needs to take more time to explain the whole scenario to students who don’t have a background in the field the scenario describes and less time for students who are more expert in that field. The instructor noted:

For students, our challenge is that the general population is given enough background so that they see that big picture. . . . In the bigger class lecture for the entire population, we have many that sometimes don’t even know what a pig is, or a gilt, or because they’re so unfamiliar with that system it just takes a while to explain it to them. . . . If we try to hit the whole big scenario, sometimes it’s too complex. Like the scouring. . . . for somebody who doesn’t know, it takes a whole 40 minutes just to explain the thought process to a veterinary student. If we had all swine experts, probably it would just take 15 minutes to explain, and then they would spend too
much time arguing, you know, the accuracy and so and so forth, but they would have
the concept well.

The third challenge the instructor perceived was trying to achieve a balance between
integrating systems thinking into the curriculum for the purpose of passing the course and the
NAVLE versus for the purpose of achieving success in practice. Systems thinking focuses
on the big picture, whereas the NAVLE is more specific, requiring a very structured thought
process with less attention to the big problem, e.g., the preventions and treatments for
rotavirus and E. coli (i.e., choosing what diagnostic test to do for a sick animal). In the
instructor’s words:

I can do a thought process, it’s kind of like systems thinking or problem-based
learning, that covers a small thing very well, or I cover a lot of things but just very
briefly.

NAVLE, which is our benchmark, a lot of their questions are more specific . . . a
thought process, but they’re less into the big problem. . . . [It’s] very specific into a
process related to: if you have a sick animal, are you going to do x-rays, or are you
going to do blood work . . . what are the preventions and treatments for E. coli . . . for
rotavirus. . . . It’s a very structured process. . . . They don’t try to get things in the big
perspective because they’re trying to get a correct answer.

Unfortunately, with time there’s so many of these other things, it’s hard to figure out
what you’re going to be able to cover.

Ideally, we want the students more competent, and that’s why I think it was important
to incorporate this.
The fourth challenge was that the overall case load at the clinic was insufficient for senior students to fully participate.

Our challenge is, we have our clinicians, we have residents who are required to get a case load, then we have senior students. And that’s the hierarchy. The residents are more likely to get the hands-on [experience], because they have to get the hands-on for their certification, and the students will observe more. But if they’re just observing, how much are they really learning, in small animal?

In food-animal, we give them a lot of hands-on, because we have larger facilities and we can go and give them that exposure. But that’s always the challenge between the clinical and nonclinical.

*The improvement needs on teaching with systems approach.* The discussion of the need for improvements in systems approach teaching is guided primarily by the instructor’s responses to interview questions 4 and 5 (Table 4.9). These questions focused on the best timing to learn systems thinking and the instructor’s suggestions in general for learning, teaching, and student assessment. The instructor suggested several techniques that would improve how the systems approach was taught. For instance:

After describing the scenario, we indicate our goal to solve this problem in the beginning of instruction, then we give the list of diagnostic questions. That way we can lead them to systems thinking.

Come up with a scenario that can be broken down into parts, and then [say], “Okay, this part is addressing this, this part is addressing this, and this part’s addressing that,” and if they were independent, then you could work it just in small pieces and then put the whole scenario back together.
The best timing for a brief introduction is in the first year, with detailed systems thinking introduced at the end of the third year, right before the fourth year. This is because a foundation is needed to get the true picture.

We all know the basics of trees, and it made sense, so if we could come up with something like this related to livestock, that would be good in your first year. . . . We need students to have some of that basic information so that they know how this all applies. . . . At the end of the third year, they have enough of the basis foundation.

When assessing students’ understanding, a goal for problem solving needs to be clarified to narrow down the direction. The instructor noted, “Depending on the goal we give [the students] is where we could direct them.”

Discussion

Design Experiment 3 was intended to assess whether the instructional changes made based on the results of Design Experiments 1 and 2 led to the improvement of students’ ability to apply systems thinking to veterinary health case scenarios. The major changes from Design Experiments 1 and 2 were to increase the amount of instruction students received by including a second topic in systems-approach instruction and to assess students on multiple topics, including some on which they had received instruction and some on which they had not. The first change would help in the assessment of the direct effect of instruction and the second change would help to assess the ability to transfer systems thinking to new topics. Specifically, students received systems-approach instruction on the topics of goat and swine. They were assessed on goat and swine as direct assessments of learning. Transfer was assessed by testing students on two problem scenarios involving chemical hazards and a problem involving beef.
The research question for Design Experiment 3, as for the first two design experiments, was: Do systems-approach interventions lead to changes in students’ systems thinking? The project team had hypothesized that students would show improvement from the pretest to the posttests on both direct and transfer assessments and demonstrate a higher level of systems thinking subsequent to instruction than they did prior to instruction. Four areas of key findings—direct effects of instruction, transfer effects of instruction, factors that promote learning and transfer applied to this study, and quality of the assessments—for Design Experiment 3 are discussed next.

**Direct effects of instruction.** The repeated measures ANOVA on the overall pretest and posttests showed that students improved from the pretest to both posttests in their ability to select systems-approach diagnostic questions from a set of possible diagnostic questions. In addition, the performance on both the goat1 and swine assessments, which assessed learning of content directly covered in the instruction, improved significantly from pretest to posttest. These results demonstrated that students, given a problem scenario about which they had received some systems approach instruction, were more likely to select systems-approach-based diagnostic questions than they had been before.

**Transfer effects of instruction.** Results with respect to transfer were mixed. The chemical1, chemical2, and beef sub-problem scenarios assessed transfer. There were no significant improvements from pretest to posttest for the chemical1, and chemical2 sub-problem scenarios; thus, there was no evidence of transfer on these subtests. There was a significant improvement from pretest to posttest for the beef scenario, demonstrating transfer of systems thinking to a topic for which systems-approach instruction was not provided. However, the similarity between swine and beef production systems was probably the reason
that transfer occurred. Ultimately, the goal of all veterinary instruction is to develop a base of knowledge and thinking/reasoning skills that the practitioner can apply to new situations.

The results on both the direct and the beef transfer assessment clearly demonstrated that the systems approach instruction had some success in achieving its goal of helping students use a systems approach in thinking about health problem situations in agricultural production. However, the approach did not transfer to all of the nondirect assessments.

**Factors that promote learning and transfer applied to this study.** There was no evidence that the increase in instructional effort in Design Experiment 3 led to greater learning. There was no significant difference for the performance between students who had extra intervention in either VDPAM 419x or VDPAM 310 and those who did not. It is not surprising that transfer was limited, as transfer is often difficult to obtain (Bransford & Schwartz, 1999; Detterman, 1993; Schwartz, Bransford, & Sears, 2005). Instructional factors that promote transfer of learning include the degree of original learning. A number of findings about instructional features that support transfer were summarized by Bransford and Schwartz (1999). The degree to which retrieval of learned knowledge is effortless facilitates transfer. Particularly important is instruction that promotes deep conceptual understanding as opposed to repetition of particular content or skills. Providing students with experiences in multiple and different contexts in which the to-be-learned concepts, principles, skills, and ways of thinking occur can also lead to broader transfer. Encouraging students to think about new content in problem solving or application situations leads to greater transfer (Bransford & Schwartz, 1999). Case-based, problem-based, and project-based learning using several contexts encourage students to think about the abstract features that are similar across different problem situations. Inventing “solutions to a broad class of problems” (Bransford
& Schwartz, 1999, p. 5) is another instructional method that encourages transfer. Another important instructional approach that improves transfer of an intellectual skill is to demonstrate to students that the new skill is more effective than alternative approaches (Pressley & McCormick, 1995). These suggestions are consistent with the instructor’s responses in the need for faculty training.

Some of these above-mentioned teaching strategies existed in the present instruction, in part as a result of design changes developed in response to Design Experiment 1. As noted above, more content involving the systems approach was incorporated into lectures and the systems approach was applied to two topics (swine and goat) in the class. Each topic and the simulation demonstration were taught by a different instructor. The total duration of systems approach teaching was roughly two hours on four different dates. Additionally, some students were taking VDPAM 310 concurrently, which involved one 60-minute systems-thinking lecture by the systems trainer and a 30-minute quiz on systems thinking. Two scenarios (beef and chemical hazard) were added to the assessment to determine whether students were able to transfer their ability on systems thinking from the swine and goat scenarios that were taught in the class to beef and chemical-hazard scenarios that were not taught in the class.

This increase in instructional effort did not lead to improved performance on the common swine items on the pre- and posttests. In addition, as noted above, there were no significant differences between the performances of students who had received systems-approach instruction in VDPAM310 and students who had not. In addition, there were no score differences between the initial systems approach class in Design Experiment 1, which received only one scenario, and the class in Design Experiment 3, which had more
intervention lectures and in class scenarios. Although reading a related chapter before running a simulation might have helped, there was no significant relationship between results for students who had extra intervention with PowerPoint slides provided in advance and the results of those who did not have the extra intervention. Perhaps still more practice with a variety of examples and rich feedback is required to produce a measurable difference.

Another issue might be that the change to a systems approach requires a conceptual change or a new way on the part of students to think about learning in school. Students in Veterinary Medicine are typically very good at memorizing and providing answers on traditional exams. Instead of asking for memorization of details or thinking about individual diseases, the systems approach asks students to think about the overall pattern of the data provided in the problem scenario and related patterns to the general problem of how one maintains the health of the herd or the security of the food system. The systems approach requires a change in thinking style, and such a conceptual change is often difficult for students to achieve unless the instructor is particularly careful to make the idea clear (Pea et al., 1991). Usually, students must be exposed to and process any new thinking approach multiple times to change their beliefs and practices and incorporate the new approach into their conceptual system. Sometimes guidance with a lot of examples is necessary to help them to see why and what they need to change, how they are supposed to learn, and what is important to learn.

The students also were not given feedback on the tests. Providing feedback and relearning opportunities can also increase instructional effectiveness with respect to transfer. Thus, students could not learn from mistakes or be sure if they had selected the correct questions. Asking experts such as the systems trainer to provide feedback, including the
reasoning involved, about the choices on practice scenarios and diagnostic questions and to explain why the systems approach diagnostic questions are more powerful diagnostic tools at the level of the system than are the non-systems diagnostic questions could also improve the power of the instruction to effect change.

**Quality of the assessments.** The use of direct and transfer assessments in Design Experiment 3 allowed at least some degree of transfer to be demonstrated. This improvement in the assessment approach from Design Experiment 1 was thus a valuable change in Design Experiment 3. However, part of the problem with the relatively low performance of students in Design Experiment 3 may have been the quality of the assessment.

Although student improvement was shown from pretest to posttest, the Cronbach’s coefficient alpha and correlational analyses revealed that performance was not consistent across the correct (systems-approach-based) diagnostic questions. Diagnostic questions within and across topics correlated negatively with each other. These results suggest that, although the instructors had perceived these as systems-approach diagnostic questions, the assessment items were not sufficiently reliable and more care needs to be taken to clearly define and evaluate what constitutes a systems-based question. Furthermore, the assessments asked students to select the “best” diagnostic questions to ask. The assessment items did not specifically ask students to select systems-approach diagnostic questions. Students might not have yet reached the level of understanding to lead them to select only systems questions as the best questions. Approaches to assessment that might help to reveal the nature of students’ understanding might include asking them to specifically select systems-approach questions and/or to generate systems-approach diagnostic questions. Schwartz et al. (2005)
discussed research that demonstrated that traditional test formats may not reveal all knowledge that transfers. However, those assessments in which students were asked to describe how they might go about learning to deal with new problems revealed developmental change in problem solving. Such changes might increase the reliability of assessment and increase confidence that the assessments better reveal students’ understanding of application of the systems-thinking approach to veterinary health issues.

**Discussion of qualitative results**

**Student interviews.** Students spent approximately 15–60 minutes to complete each of the pre- and posttests and preferred more time to complete them either in the class or outside of class time. Student H spent approximately 20 to 30 minutes on the pretest outside of class. She wished she had more time to look at the graphs in the beef scenario. She also provided suggestions for improving the test format and design, such as more space on the screen and picking five instead of 10 diagnostic questions in one scenario. Student I spent 12 to 13 minutes for the pretest outside of class and less time for the posttests in class. She was a fast reader and quickly became familiar with the questions in the posttest. Student K spent 10 to 15 minutes on each of the tests. Student L spent 20 to 30 minutes outside of class just to process the pretest and 15 minutes quickly skimming and analyzing the posttests in class. She thought her posttest answers were not as carefully thought through as were those on the pretest. Student J spent a maximum of 15 minutes on the tests and less time on the posttests than on the pretest. Student M spent one hour on the pretest and 30 minutes on the posttests. She was rushed in answering the last question during the posttests in the class.

**Understanding of systems thinking.** Most of the students who were interviewed seemed to have a broad general understanding of systems thinking. They expressed their
understanding of systems thinking in their interviews. For example, Student H looked at the big-picture perspective from an operational view and thought about how all the elements might be impacted. She did not focus on a certain disease to treat as a veterinarian but considered a number of other things that could be managed. Student I thought the focus of systems thinking is more on recognizing all the factors flowing to the individual animal, trying to get the whole picture, and addressing different factors that could be playing into what’s going on. Student L considered systems thinking as backwards thinking involving thinking through the clinical science that was presented to get to the disease rather than working on the disease and expecting certain clinical science results. She thought systems thinking is working through the logic of how one approaches a problem, keeping her focused. With big-picture performance indicators, she was less likely to overlook something. Student J believed that, from a systems-approach point of view, one needs to know everything that affects the situation: staffing, protocol, cow–calf management, milking-herd management, hand washing, sanitation of the environment, vaccination status of a cattle, infectious disease agents that may cause that infection, pasture, any type of parasiticides used, where they’re using milk, where their milk end-product is going to go, who they are selling to, what the market is, and more of the basis behind it. It made so much more sense to her than simply rote memorization that an agent causes a particular disease. Student M thought that taking a step back and looking at everything overall, determining how changing one thing may have a ripple effect down the line, and avoiding focusing on details, helps one see the big picture.

However, there were clearly some important misconceptions about systems thinking. Some students were not able to fully understand the concept. For example, Student K could not define systems thinking, although she indicated it was not new to her. She thought
systems thinking was useful only as a review at the end of the section. Some students believed systems thinking applied only to macro systems, such as food production, but not to micro systems, such as individual small-animal biology systems. Student I was not sure how to approach problems using systems thinking. Students H and L were confused by the design of the pre- and posttests. Furthermore, the Stella modeling process itself proved confusing for some students. Student I was overwhelmed with the numbers and graphics when the Stella simulation model was introduced, and Student L indicated that it was too time-consuming to build a Stella model from scratch.

Some students suggested that, in order to understand systems thinking thoroughly, instruction should start earlier, perhaps in high school when learning informatics, during the first two years of undergraduate studies, or during the first year of Veterinary Medicine. They expressed that environmental classes in high school and science classes in college would have been a great place to introduce the concepts. Student L thought it would be helpful to discuss how each part of the lecture ties into the overall system. Student I thought practicing in different scenarios would have helped her better understand systems thinking. Student K believed in hands-on exercises, experiencing real work as in an internship, and PowerPoint slides as a study source. Student J would have liked to have the math behind the systems model explained and used in hand exercises. Other suggestions included:

- Breaking the class up and providing a tutorial just for people with large-animal knowledge;
- Providing an overview on the first day of the class so everyone is on the same page;
- Having more classes using it throughout the Vet school;
• Having a concurrent course that utilized systems thinking on a topic such as shelter medicine, beef records, or VDPAM 310;
• Having an elective or online lecture talking specifically about systems thinking;
• Spending at least one hour per species over four species’ categories;
• Teaching the concepts conventionally at the end of a main topic;
• Including more real-life examples, such as small animals, and working through them with a number of exercises
• Continuing systems-thinking application and practice in the clinic, rotation, and internship, but not in the classroom;
• Incorporating live animals;
• Including, for example, aquaculture or exotic zoo cases for students to relate to a scenario that was not covered in the curriculum;
• Having instructors explain how they thought through a case and how they had to change their thinking
• Providing PowerPoint slides for review;
• Having articles, a VIN thread, or a CE where people can talk about how a systems approach was actually used and how it’s beneficial;
• Providing graphs for the diagnostic questions in the scenarios;
• Not overpowering with information;
• Having positive reinforcement;
• Role playing in the project assignment, and
• Having herd data and a Stella model template provided so they could play with the numbers.
In addition, to increase interaction for the intervention; some students suggested the following:

- Talking to the professor first;
- Using a device, such as a clicker, or an online application, such as an RW poll;
- Teaming up students in the beginning of the semester and having them sit in the same area to avoid the shuffle;
- Responding to the instructor’s questions as a team, and including incentives;
- Discussing a scenario and presenting the solution in the class as a team;
- Following the instructors on the job out to a farm or a feedlot operation during the fourth-year rotation,
- Talking to clients one on one to see the problems they’re dealing with day to day, and all the different components that a veterinarian has to consider as part of the system.

Some students believed systems thinking would benefit differently depending on whether students were focused primarily on small animal or large animal health.

*Perception of the effectiveness of the instruction.* From the individual students interviews, most students had not learned systems thinking prior to this class. However, as in Design Experiment 2, all six interviewees claimed that the idea of systems thinking was not new to them because it was either taught in other courses such as food-animal, beef records, case studies, and other swine classes either before or concurrent with this class or it was used in previous agricultural or production jobs.

Three students believed that the instruction improved their ability to diagnose a systems problem. Student J believed her systems-thinking ability was enhanced after the
intervention lectures. However, only two of those interviewed in Design Experiment 3, as opposed to all five interviewed in Design Experiment 2, indicated that the instruction on systems thinking in this course didn’t affect their ability to diagnose a problem in a production system at all. Most students (H, J, K, L, and M) applied previous knowledge to complete the pre- and posttests. Student L made decisions based on previous knowledge, and Student J thought that such effects would occur with time when she entered her fourth year. A systems approach helped her in identifying rather than diagnosing a problem. Also, student H used an elimination technique because she did not know what the systems diagnostic questions were. Student M applied basic medical and research knowledge to the problem, then added in the species. Student K thought it was necessary to know all the terminology before working through the problems.

Concerns of learning and teaching systems thinking. Although some students were doubtful about the usefulness of systems thinking, other students were concerned that systems thinking was missing in the Veterinary Medicine curriculum. For example, the current beef records course could have established a structure using a systems approach. However, in general, the lectures at Veterinary Medicine presently were helping students learn a piece of each system at a time, and the professor may or may not be tying the systems together as a whole in a conclusion lecture. Some students expressed the idea that the design of the current curriculum could make it more difficult to master systems thinking because a lot of instruction emphasizes mastery of elements of the system without adequately tying them back to the whole. Some courses were trying to teach diagnostics, but they seemed to be doing it in name only. A lot of professors went into many random and tiny details assuming that everybody had the background to understand them. It was hard to consolidate
the material because it made little sense to memorize facts that they probably couldn’t or wouldn’t use. An elective class incorporating mathematics for systems thinking might be helpful.

Students, from the viewpoint of learners, provided very useful comments that could help improve future systems-related projects. For instance, they indicated that, not only does the curriculum need to be evaluated as a whole, but also the background knowledge needs to be introduced in the beginning of the class. That way, students could be on the same page and those who are on different tracks could avoid cognitive overload. In addition, students need a lot of hands-on practice in the real-world environment, such as an internship, to help them fully understand the advantage of utilizing a systems approach.

**Instructor interview.** The instructor identified a number of areas of concern in teaching a systems-thinking approach including: (a) the need for faculty training, (b) the challenges of implementing systems thinking, and (c) the improvement needed for teaching with systems approach.

**Need for faculty training.** During the instructor’s interview, the instructor expressed concern about the frequency and content of systems-thinking training for faculty. Training exercises offered each semester or each year might help faculty refresh their systems-thinking skills given that they may not have used them for a year since the last time they engage in teaching.

The instructor believed that all faculty at Veterinary Medicine should get trained each semester or annually with at least a 1-hour overview and 2 or 3 hours to study multiple examples. An entire hour with multiple examples would be better than one very thorough example because it would better allow faculty to see patterns and sense how systems-
thinking skills were applied to each case. A comparison with a familiar engineering example and a Veterinary Medicine example would be helpful in incorporating the concepts.

Moreover, the instructor believed that all Veterinary Medicine faculty should have multiple hours of training on the details of each systems-thinking skill, because the concept of systems thinking is too broad and hard to absorb without training. The content of the training should focus on each skill of systems thinking to develop two or three scenarios. He believed scenario diversity would help faculty see patterns, link, connect, incorporate, apply, and get a sense of systems thinking in Veterinary Medicine.

To improve the scenarios, the instructor suggested developing a scenario target on a specific systems-thinking skill, see the process of examples that can be related to Veterinary Medicine, and choose among the eight systems thinking skills that are more strongly related to or more easily to applied to Veterinary Medicine. The instructor believed that a little better understanding of the eight systems-thinking skills with good examples related to each scenario being studied is necessary, because it is hard to see the link, even for the trained faculty who grasp the concepts.

In addition, having Stella application experts in the group training would be useful for the group to assist in building models. It would take about an hour to understand the overall concepts of Stella application and probably at least 5 hours more to discuss being thorough and double-checking all inputs for correctness without even performing design. The tutorial created by the Stella expert helped.

Challenges of implementing systems thinking. The instructor found a number of challenges in implementing systems thinking. These challenges could be classified into four areas: the classification of diagnostic questions, getting all students on the same page,
balancing systems-thinking instruction needed for practice with instruction needed to pass the course and the NAVLE, and the lack of caseloads to provide students hands-in experience.

The first challenge was that the instructor and experts had difficulty classifying some diagnostic questions as either a systems-thinking or a non-systems-thinking questions. There are grey areas, such as direct versus indirect relationships, in the process. They did not fully understand systems thinking and how to apply it. In addition, they believed that systems thinking was only for macro and not for micro systems, for big animal populations and not individual small animals. Faculty need more explicit explanations about why a specific diagnostic question is a systems or non-systems question in a variety of examples. They also need to know what the advantages are for using a systems approach to ask questions. Practice creating diagnostic questions that included systems thinking could help them with learning the patterns.

The second challenge was that the instructor needed to spend a significant amount of class time making sure that all the students in this large class were at a level that they could understand the scenario (e.g., by providing a swine background for students not on the swine track); background had to be established first. When a systems approach is first introduced, it might take extra time to familiarize some students with the topic. However, if a systems approach were adopted throughout the curriculum, each faculty would need to provide just a brief introduction in combination with the particular subject matter. A variety of case scenarios that includes big and small animals, shelter, zoo, and other animals needs to be created.
The third challenge was that the instructor tried to achieve a balance between integrating systems thinking into the curriculum for the purposes of passing the course and NAVLE veterinary exam and achieving success in practice. NAVLE doesn’t emphasize systems thinking. However, incorporating systems thinking into the NAVLE-based curriculum could help students better implement the subject matter in practice. What counts in assessment is what drives curriculum!

The fourth challenge is that the College of Veterinary Medicine doesn’t have a case load for everyone. The residents are more likely to get hands-on experience, because they must have it for their certification, and the students are more likely to just observe. However, students generally retain knowledge by doing, and if they’re just observing, it brings into question how much they are really learning. They need to get hands-on experience as well. The college should provide other sources, such as internships, for students to practice systems thinking in the real world.

*Improvement needed in teaching with systems approach.* Some teaching techniques were suggested by the instructor. These techniques would help instructors lead students toward systems thinking.

First, the instructor believed that, because a foundation is required to achieve understanding of systems thinking, the end of the third year is the best timing for detailed systems thinking. However, a brief introduction to systems thinking should be given in the first year of the Vet school curriculum. Second, an understanding of systems thinking should include being able to interpret systems thinking by breaking down a scenario, explaining the function of each part, and then putting the whole scenario back together. Third, at the
beginning of instruction, after describing a scenario, the instructor should state the goal of solving the problem, then give the list of diagnostic questions.

Next, students need a visual image to see the benefits of using a systems approach. The instructor needs to clarify the goal of problem solving using a systems-thinking approach and go through multiple case scenarios with students. However, the scenarios were not fully explained, and only four scenarios were created and utilized. Furthermore, with so few scenarios, students could have memorized the answers if the instructor explained how to distinguish each single diagnostic question. If there were a database comprising a variety of scenarios, the instructor could pick the one most related to the subject matter and explain it in detail, such as identifying the systems versus non-systems questions and why.

Finally, students need to be shown the differences in outcomes when using a systems approach versus using a traditional approach. Creating scenarios and applying a systems approach to the Veterinary Medicine curriculum is teamwork; all faculty need to work together to make it success.

**Limitations.** First, this initial incorporation of the systems approach into veterinary instruction at ISU was minimal. Students received four 50-minute lectures comprising a discussion of alternatives for two specific scenarios presented in the assessment. Similar to Design Experiments 1 and 2, the main reasons for this low level of instructional intervention exposure were the complexity of integrating new ideas into an already densely packed syllabus in the course and the time needed for busy instructors to process of new ideas so as to integrate them fully into the curriculum. Comments by the interviewed students about their need for more instruction and the instructor’s comments are consistent with the view that the integration of systems approach ideas into the curricula of the vet met program, in
general, and the individual classes, in particular, was minimal. In addition, only four scenarios were created. Although the swine scenario was fully embedded in the swine segment of the course, the goat scenario was only briefly introduced (a 6-minute introduction) using the Stella simulation systems model in the ruminant segment of the course because the instructor thought goat alopecia was one of many diseases to be covered in the syllabus. Because of this limited exposure, students were not able to see the pattern of the systems-thinking approach from the scenarios.

Second, the results do not provide clear evidence of transfer of understanding or the efficacy of the instruction to new situations. Similar to Designs Experiment 1 and 2, the first exposure to the assessment items on the pretest represented items that were unfamiliar to the students, as the students received instruction on the same swine and goat scenarios after the pretest, during the initial lessons. However, also similar to the first two experiments, the same swine and goat scenarios and test items that were used for the instruction were also used for the posttests. The final posttest was given in class right after the fourth intervention lecture.

Third, students, given the limited instruction, could have been too cognitively overloaded with new knowledge on dynamic systems modeling with simulation to learn a new concept. The simulation used Stella application models to show the differences on the dynamic systems. When all the factors showed in the big picture, students might have been overwhelmed seeing so much to learn at once besides getting to know the application.

**Summary**

This chapter described the three design experiments conducted as part of the design research project to incorporate systems thinking into Veterinary Medicine education.
Instructors, instructional designers, and systems trainers worked together to plan and incorporate the systems approach and systems thinking into the Veterinary Medicine curriculum. The instruction was designed to lead students to use systems thinking in diagnostic problem solving. The students, course, instructors, design of the course, subject matters, and class environment were different in each of the three design experiments.

Design Experiment 1 implemented the systems content using one topic (swine) in one Veterinary Medicine class. Students were assessed with one pretest and two posttests to evaluate their ability, given a health issue scenario, to select five systems diagnostic questions and eliminate 15 non-systems diagnostic questions. Performance improved significantly from pretest to posttests. However, students still selected fewer than 50% of the systems diagnostic questions on the final posttest.

Design Experiment 2 also implemented the systems approach content using two topics (swine and goat) in one Veterinary Medicine class. Students were assessed with one pretest and one posttest to evaluate their ability. They were given two health-related scenarios (one for swine and one for goat) and asked to select five systems diagnostic questions and eliminate 15 non-systems diagnostic questions for the swine scenario and, for the goat scenario, to select 4 systems diagnostic questions and eliminate 16 non-systems diagnostic questions for the first sub-problem scenario and to select 5 systems diagnostic questions and eliminate 14 non-systems diagnostic questions for the second sub-problem scenario. Performance improved slightly from pretest to posttest. However, students still selected fewer than 50% of the systems diagnostic questions on the posttest. In addition, most students were not sure how to apply systems thinking, even though the concept was not new to them.
Design Experiment 3 implemented the systems content for two topics (swine and goat) in one Veterinary Medicine class. Students were assessed with a pretest and two posttests. They were given four health-related scenarios (swine, goat, beef, and chemical hazard) and were asked to select five systems diagnostic questions, eliminating 15 non-systems diagnostic questions for the swine scenario, eliminating 17 non-systems diagnostic questions for the first goat sub-problem scenario, eliminating 14 non-systems diagnostic questions for the second goat sub-problem scenario, eliminating 12 non-systems diagnostic questions for the first chemical hazard sub-problem scenario, and eliminating 11 non-systems diagnostic questions for the second chemical hazard sub-problem scenario, and to select 10 systems diagnostic questions and eliminate 10 non-systems diagnostic questions for the beef scenario. According to individual interviews, more students expressed better understanding of systems thinking in Design Experiment 3 than in Design Experiment 2. These interviewed students could describe systems thinking in depth and provide examples of how to use systems thinking in a real-world situation. In addition, their performance improved significantly from pretest to posttests. However, students still selected fewer than 50% of the systems diagnostic questions on the final posttest.

Differences Among the Three Design Experiments

The three experiments reported in this chapter exemplify a design research approach to instructional development. With such an approach, an implementation of a particular instructional approach is developed in an initial form. It is tried out with students, and evaluations assessing the project, typically using quantitative and qualitative approaches, are conducted with the purpose of guiding future implementations of the project. The ongoing cycles of implementation, evaluation, and redesign continue until the project achieves the desired degree of success.
Some modifications were made among in design experiments as this dissertation study progressed. In Design Experiment 1, one instructor provided two 50-minute systems-thinking instructional interventions in two classes and the length of time between these two classes was 3 weeks. The instructor embedded the swine scenario and systems thinking in the class materials. The instructor had designed the swine scenario in concert with the systems trainer, the systems graduate student, and instructional designers in spring of 2012. For the assessment, only one scenario (swine) was used. All three online tests (pretest, posttest 1, and posttest 2) were conducted in the classroom and students had 10 minutes to complete each test. The pretest was conducted on Google Forms, and the posttests were conducted on Qualtrics. No interviews were conducted with either students or the instructor. The modifications made between Design Experiment 1 and Design Experiment 2 and between Design Experiment 2 and Design Experiment 3 are outlined below.
Modifications made to Design Experiment 2 from Design Experiment 1

A. Instructional design

1. One systems trainer and one systems graduate student provided two 50-minute lectures intervention because the course instructor was not able to deliver systems thinking intervention. The length of time between these two lectures in was 1 week.

2. The swine scenario simulations were demonstrated in class but separate from existing course materials. A goat scenario simulation model was briefly used to provide an example different than the swine example on which the students were mainly focused.

3. This class used the swine scenario from Design Experiment 1 and a newly created goat scenario; an advanced swine simulation model created by the instructor in summer 2012 that was not finalized before the fall 2012 intervention.

B. Assessment

1. Two scenarios (swine and goat) were assessed in Design Experiment 2 to determine whether students could transfer their systems-thinking knowledge with respect to the swine scenario to the goat scenario.

2. There were two online tests (one pretest and one posttest) because the two intervention lectures were given within a short time period. These tests were both held during class time, and students had 10 minutes to complete each test.
3. Both tests were conducted using Qualtrics because it was efficient and supported by the university’s Information Technology department. Students could select as many diagnostic questions as they desired and submit the tests.

4. Five 30-minute student individual interviews were conducted in Design Experiment 2 to collect qualitative data.

5. There was no quantitative analysis for Design Experiment 2 results because only five students took the VDPAM 419x course and participated in the study.

**Modifications made to Design Experiment 3 from Design Experiment 2**

A. Instructional design

1. Two instructors provided a total of two additional hours of intervention lectures in Design Experiment 3 to determine whether these added lectures would further improve students’ performance. The four lectures were in weeks 8, 13, 13, and 24 of the semester.

2. The first instructor invited the systems graduate student to demonstrate a 12-minute goat-scenario simulation model in his session. However, the goat scenario was separate from the existing course materials because there was too much content in his portion to include extra material. The second instructor, who was the same instructor as in Design Experiment 1, embedded the swine scenario and systems thinking into the class material.

3. The first instructor designed the goat scenario prior to Summer 2012.

B. Assessment

1. Four scenarios (swine, goat, chemical hazard, and beef) were assessed in Design Experiment 3 to determine the ability of students to apply systems thinking
learned in the swine and goat scenarios to the chemical hazard and beef scenarios.

2. The online pretest in Design Experiment 3 was held outside of class and was conducted during the course of a week because the first instructor did not have extra time during class time for the pretest. The two online posttests were conducted in the second instructor’s class session, and students had 15 minutes to complete each test.

3. All three tests were conducted using Qualtrics.

4. Six 60-minute student individual interviews and one 60-minute instructor interview were conducted in Design Experiment 3 to examine the students’ and instructor’s point of view of systems-approach teaching.

5. One system diagnostic question, “What is the average parity of the farms?” used in the swine scenario for Design Experiments 1 and 2 was modified in Design Experiment 3 to “What is the average parity of sows?” This was done because the finding for that diagnostic question in Design Experiments 1 was not significant, and this question was not included in the reliability calculation for the system diagnostic questions between Design Experiment 1 and Design Experiment 3.

6. One system diagnostic question, “On average, how long do the animals spend in each type of pen (e.g., freshen, dry, milking)?” was added to the first goat sub-problem scenario to Design Experiment 3. This aligned the number of systems diagnostic questions in this sub-problem with the number in the other subproblems, so that students could be asked to select five (instead of four)
diagnostic questions for this sub-problem as they were asked to do for most of the other subproblems. Students were not allowed to submit the test without selecting the required number of diagnostic questions. After adding this systems diagnostic question, five systems diagnostic questions were consistently asked for in all scenarios except the beef scenario.

7. One question, “If you could have another SA classes what would you want to learn about other than the subject matter?” was deleted from the student interview guide and eight questions were added, namely: (a) Please tell me your name, class, and your background; (b) Did you learn systems thinking in any forms before this class?; (c) We have four scenarios (goat, swine, chemical hazard, beef); which ones did you learn?; (d) How did you answer to scenarios that you did not learn? (Apply what you have learned, intuition, sense, important, key points); (e) What is the best timing to learn ST?; (f) Intervention amount right to you?; (g) How long did it take you to complete the pre-/post1/post2 tests?; (h) h. Suggestions or questions in general?
CHAPTER V. DISCUSSION AND CONCLUSION

This chapter includes a summary of this study, where the purpose and research questions for the study are reviewed; a discussion of the results of the three design experiments; and conclusions, limitations, and recommendations for future research based on the empirical findings.

Summary

The purpose of this study was to investigate the application of a newly designed systems approach to the problem of Veterinary Medicine students’ lack of big-picture experience. The fundamental research questions of the study were focused mainly on determining whether the newly designed systems approach improved students’ performance with respect to incorporating systems thinking into their analysis of problem scenarios. The research questions were as follows:

Research question 1: Do systems-approach interventions lead to changes in students’ systems thinking?

Research question 2: Do the following variables contribute to changes in students’ systems thinking: qualifying exam (QE) scores, cumulative Veterinary Medicine GPA (CVMGPA) scores, and gender?

The main part of the study encompassed answering the fundamental question by determining whether the newly designed systems-approach and instructional materials interventions within existing courses improved students’ performance in veterinary case-scenario analysis. It was hypothesized that students would demonstrate a higher level of systems thinking subsequent to instruction than they did prior to instruction.

This dissertation study was part of a longer-term HEC project implementing systems thinking in Veterinary Medicine courses at ISU and KSU. For the project, systems-thinking
interventions were blended into courses in the Veterinary Medicine curriculum. An experimental design research process was undertaken by which each implementation was evaluated and the resulting insights used to inform subsequent implementations. The research conducted for this dissertation study involved design research for the first implementation of systems thinking into the Veterinary Medicine curriculum at ISU.

The second part of the dissertation study examined the impact of teaching systems thinking on students’ overall academic performance in the Veterinary Medicine program. Specifically, this study compared the regression equations between entrance-score predictors, GPA prior and post to swine-course for the four cohorts (Classes of 2009, 2010, 2011, 2012) before introducing systems thinking, and for students in the Class of 2013 and 2014, the two classes received the systems approach intervention. Questions would be raised if introducing an educational change led to deterioration in students’ performance into the program. It was hypothesized that students in the classes of 2013 and 2014 who were given systems-thinking lectures would demonstrate a higher level of academic performance than would students in the Classes of 2009, 2010, 2011, and 2012, who did not receive such lectures. Although historical and current data were used to compare students’ academic performance changes in the program before and after systems thinking was introduced, ANCOVA showed these possible covariates did not correlate with pre- or posttest performance. One possible reason for the low correlations may be the demanding selectivity of the Veterinary Medicine program. Such selectivity limits the variance with respect to these possible covariate variables, and range restriction limits the size of the possible correlations. Therefore, no further discussion for Research question 2 is included.
Empirical Findings

The primary goal of the overarching project was to develop a new framework, curricular approach, and delivery mechanism that would transform the mindset and skill set for future veterinarians tasked with safely feeding the world. The secondary goal was that the systems approach applied in this project would be widely adopted by other veterinary colleges and food science programs.

What emerged from this project was a new systems-based approach to teaching students about production animal medicine; four teaching case scenarios that could be easily implemented in new or existing courses were developed. The following instructional resources were developed to explain to students how use a systems-thinking approach to analyze food-animal production systems: four case-based scenarios (swine, goat, food safety chemical hazard, beef) and their associated diagnostic questions, Stella systems diagram simulation models corresponding to swine and goat scenarios, PowerPoint slides for the intervention lectures, pre- and posttest assessments, and student and instructor interview guides.

A series of three design experiments were used to determine the impact of this systems-based educational approach. In this design-based research approach, the researchers conducted a series of iterations of implementation, evaluation, and revision. Three iterations were conducted, with improvements to the instructional approach following each of the first two iterations. The setting and key findings of each design experiment are described in the following sections.

Design Experiment 1

This experiment involved 155 third-year veterinary students in a core Large Animal Medicine course held during the Spring 2012 semester. Two 50-minute class sessions related
to swine medicine were modified to include the systems-thinking intervention. Pre- and posttests were conducted before each intervention class session and after the second intervention class session. In the tests, students were asked to identify five out of the 20 potential diagnostic questions provided that would yield the best information for solving the problem, which involved scouring piglets in a farrow-to-wean sow operation. Students were scored based on how many of the questions they chose were from the set of five systems-oriented questions.

The results demonstrated that students’ understanding of systems thinking improved mildly. Students did significantly better at selecting systems-based questions on both posttests than they did on the pretest, and they performed better on the second posttest than on the first posttest. These results supported the proposition that the instructional intervention led to modest increases in students’ use of systems thinking in dealing with some of the swine health issues a veterinarian might face. Students developed their thinking skills after exposure to case studies related to scientific controversies such as how environmental and moral conflicts interact in a whole system (Dori et al., 2003).

**Design Experiment 2**

This experiment involved five second- and third-year veterinary students in the elective Advanced Swine Production Informatics course held during the Fall 2012 semester. Two 50-minute guest lectures in the context of swine and goat medicine were given to represent systems-thinking intervention. The pretest was conducted one week before the first intervention lecture and the posttest was conducted after the second intervention lectures. In addition to the scouring piglets in a farrow-to-wean sow operation case scenario, a milking goat with alopecia history case scenario was covered in the tests. Students were scored based
on how many of the systems questions they chose as the best diagnostic questions. Student interviews were conducted after the last intervention class session.

Based on Design Experiment 1, Design Experiment 2 incorporated an additional scenario on goat alopecia to aid in assessment of the transfer of systems thinking to new problems and the ability of students to produce systems-thinking alternatives to case scenarios. In addition, qualitative research was conducted to examine individual student reactions to the interventions and the case scenarios both in the same and different courses.

The results demonstrated that students’ understanding of systems thinking improved very slightly. Students did better at selecting systems-based questions on the posttest than they did on the pretest. However, there was no evidence that the increase in instructional effort (an extra case scenario) in Design Experiment 2 led to greater learning. In addition, the magnitude of the improvements was low (about 16% from pretest to posttest). There was insufficient statistical capability for providing evidence of change between the pre- and posttests because of the low number of participants. Therefore, the results section focused on a qualitative content analysis from the observational data and the interviews.

According to the qualitative analysis, two key themes emerged: students’ understanding of systems thinking and their perception of the effectiveness of the instruction they had received.

**Understanding of systems thinking.** Although four students were not able to apply and transfer their understanding of systems thinking to a new situation, their interpretation of systems thinking demonstrated some understanding of the concepts. They indicated that the systems approach is efficient to “identify and prioritize risk factors” and “help you in the end know where to focus.” The techniques they described included “zoom out” and “looking at
the overall picture but also individual animals” as well as taking “all of the variables into account” to determine “how everything is interconnected and what the relationships are between every piece of the puzzle.” Their understanding of cross-disciplinary boundaries was as “understanding the context,” “looking at flow or progression of things and everything that goes in and out of the system,” “what’s changing,” and “how the other parts are interacting with that.”

**Effectiveness of the instruction.** Most students already had had a perception of the production industry and claimed that the ideas underlying systems thinking were not new to them prior to intervention. Therefore, they claimed the instruction on systems thinking in this course didn’t enhance their ability to diagnose a problem in a production system. However, most of the students indicated that “we should have [gone] over the assessment at the end to see if we really understood the concept,” and that it was important to “explain to people why we do [it] and how it’s done.” “You really just got to work through problems until you start to get it.” In addition, two students thought “to ask the right questions, you’re kind of looking at your most likely things based off experience and based off what you’ve learned.” “There’s no way you can work your way through the problems later if you don’t understand all the terminology.” These statements showed that students in this class did not understand systems thinking entirely and how to apply it to the problem solving in the food production system.

**Design Experiment 3**

This experiment involved 147 third-year veterinary students in the core Large Animal Medicine course in held during the Spring 2013 semester. Four 50-minute class sessions dealing with swine and goat medicine were modified to include systems-thinking intervention. The pretest was conducted outside of class before the first two intervention
class sessions, the first posttest was taken at the beginning of the second intervention class (first swine intervention class), and the second posttest was taken after the last intervention class session. In addition to case scenarios concerning scouring piglets in a farrow-to-wean sow operation and a milking goat with alopecia history, scenarios concerning a food-safety chemical hazard involving a pork-packing plant and a beef cow-calf situation were covered in the tests. Students were scored based on how many of the systems-thinking questions they chose.

Quantitative findings. According to the quantitative analysis of the pretest and posttests, there were four key findings: (a) the direct effects of instruction, (b) the transfer effects of instruction, (c) factors that promoted learning and transfer, and (c) the quality of the assessments.

Direct effects of instruction. The results demonstrated that students’ understanding of systems thinking improved very slightly. The magnitude of the improvements was low (about 10% from pretest to posttest1, 18% from pretest to posttest 2, and 7% from posttest 1 to posttest 2). Nonetheless, students did significantly better at selecting systems-based questions on both posttests than they did on the pretest, and they did better on the second posttest than on the first posttest. These results supported the proposition that the instructional intervention led to modest increases in students’ use of system thinking in dealing with swine, goat, and beef health as well as with food safety issues a veterinarian might face.

Transfer effects of instruction. There was no evidence of transfer on the goat2, chemical1, and chemical2 sub-problem scenarios, as there were no significant improvements from pretest to posttest for these scenarios. However, there was a significant improvement
from pretest to posttest for the beef scenario, demonstrating transfer of systems thinking to a topic for which systems-approach instruction was not provided. Although the approach did not transfer to all of the non-direct assessments, the results on both the direct assessment and the beef transfer assessment clearly demonstrated that the systems-approach instruction had some success in achieving its goal of helping students use the systems approach in thinking about health-problem situations in agricultural production.

Factors promoting learning and transfer in this study. There was no evidence that the increase in instructional efforts (two extra hours and two extra case scenarios) in Design Experiment 3 led to greater learning. Perhaps yet more practice with a variety of examples and rich feedback are required to produce a measurable difference. As Frick and Koh (2007) indicated in their study, teachers’ instruction and information clarification, along with students’ independent decision making, feedback, interaction, partnership, teamwork, and social activities, can improve students’ learning. Providing explicit, specific scaffolds for performance support helped students in developing higher-level systems thinking (Assaraf et al., 2013).

Quality of the assessments. The use of direct and transfer assessments in Design Experiment 3 demonstrated at least some degree of transfer. However, the Cronbach’s coefficient alpha values and correlational analyses revealed that performance was not consistent across the correct (systems-approach-based) diagnostic questions. Diagnostic questions within and across topics correlated negatively with each other. This suggests that the assessment items were not sufficiently reliable and that more care should be taken to clearly define and evaluate just what constitutes a systems-based question.
As in Design Experiment 1, students in Design Experiment 3 improved significantly from pretest to both posttests and from posttest1 to posttest 2. The magnitude of the improvements in all three pretest/posttest comparisons was modest; Cohen’s $d$ effect size statistic averaged .62 across 12 comparisons ($SD= 0.30$). Students tended to do improve slightly more than one-half of a standard deviation on a subsequent test compared to a prior test. Effect sizes were larger from pretest to posttest 2 ($M = 0.86, SD = 0.27$) than from pretest to posttest 1 ($M = 0.47, SD = 0.18$).

Although based on Design Experiment 2, Design Experiment 3 incorporated a greater number of scenarios across a greater range of food production and processing safety and health issues, the assessment of the transfer of systems thinking to new problems, and the ability of students to produce systems-thinking alternatives to case scenarios. The interventions were performed multiple times to encourage students to utilize systems thinking. To gain in-depth knowledge of both the instructor’s and students’ understanding of systems thinking, interviews were conducted with both students and the instructor after the last intervention class session.

**Student interviews.** According to the qualitative analysis of student interviews, one student believed her systems-thinking ability was enhanced after intervention lectures, whereas another student thought this would come with time in the fourth year. One student indicated that the systems approach helped her in identifying instead of diagnosing a problem. Half the students needed 15 minutes to complete each test, whereas the other half needed 30 minutes; the latter group preferred more time to complete the tests in the class or to do them outside of class. Two key themes emerged: students’ understanding of systems thinking and their perception of the effectiveness of the instruction they had received.
**Understanding of systems thinking.** Most of the students interviewed seemed to have a broadly accurate understanding of systems thinking, describing it in terms such as understanding “the big picture perspective,” how “changing one thing will have a ripple effect down the line,” or “taking a step back and looking at everything overall.” However, there were clearly some important misconceptions about systems thinking. One student could not define systems thinking, although she indicated it was not new to her. Another student indicated that systems thinking is useful only at the end of the section as a review. Several students indicated that systems thinking is useful only for macro systems, such as food production, but not for micro systems, such as individual small-animal biological systems. Furthermore, the Stella modeling process itself proved confusing for some students. One student indicated that when the Stella simulation model was introduced, she was overwhelmed with the numbers and graphics, and another indicated that it was too time-consuming to build a Stella model from scratch.

**Effectiveness of the instruction.** Similar to Design Experiment 2, all six participants in Design Experiment 3 indicated that they already had known something about systems thinking before starting this course. Three students interviewed in Design Experiment 3 believed that the instruction improved their ability to diagnose a systems problem. However, only two of those interviewed in Design Experiment 3, as opposed to all five interviewed in Design Experiment 2, indicated that the instruction on systems thinking in this course didn’t affect their ability to diagnose a problem in a production system at all. In addition, four students also expressed the view that the design of the current curriculum can make it more difficult to master systems thinking because a lot of the instruction emphasizes mastery of elements of the system without adequately tying them back to the whole.
**Instructor interview.** According to the qualitative analysis of the instructor’s interview, the instructor indicated four challenges in implementing systems thinking. First, both the instructor and the experts found that grey areas in the relationships between specific questions and the broader system made it difficult to consistently classify a diagnostic question as either a systems or a non-systems question. Second, the instructor needed to spend precious class time to get all the students in this big class on the same page (i.e., provide swine background for students who were not on the swine track). Third, time spent on emphasizing systems thinking affected the instructor’s ability to adequately cover other material essential to passing the course, passing the NAVLE veterinary exam, and succeeding in practice. Fourth, the case load in the teaching hospital’s clinic does not always provide all students with adequate opportunities to practice the concepts discussed in the course, including systems thinking. Often, residents do the hands-on work while students observe, somewhat limiting student learning.

**Overall Findings**

Across all three experimental design studies, the instructional intervention led to modest but statistically significant increases in students’ use of system thinking. Furthermore, there was a significant improvement from pretest to posttest for the beef scenario, demonstrating the transfer of systems thinking to a topic for which systems-approach instruction was not provided. Therefore, it is safe to conclude that the experimental instruction had some success in achieving its goal of helping students use the systems approach in addressing problems in production-animal medicine.

From the qualitative analysis, most students found systems thinking to be beneficial for macro systems, such as food production, but not for micro systems, such as individual small-animal biological systems. Some students were concerned that systems thinking was
missing in the Veterinary Medicine curriculum. For example, beef records did not implement a structure using a systems approach. The present lectures at Veterinary Medicine generally helped students learn a piece of each system at a time, and the professor may or may not tie the material together as a whole in a conclusion lecture. Students indicated that it is hard to put the material together because it makes no sense just memorizing material they can’t or won’t use.

On the other hand, the instructor indicated that some challenges were encountered in implementing systems thinking. First, the instructor had insufficient training and support in mastering systems thinking. Second, it was time-consuming for both the instructor and the students to learn knowledge beyond that in the current curriculum. Third, hands-on clinical experiences with systems thinking are considered to be more important than lecture or observation; however, the opportunities for such experiences were limited.

These design experiments demonstrated that the project achieved some degree of success in leading students to improve their ability to select systems diagnostic questions in veterinary health-problem scenarios from the pretest to the posttest(s). The findings also highlighted concerns that students and instructors had about making the innovation more successful. Making changes in an existing curriculum is always complex. There is a human system of instructors and accrediting agencies that constrain the nature and pace of changes. Knowledge in any field, including Veterinary Medicine, continues to expand, and instructional time generally does not. Decisions must be made about what to include or not include among different content in Veterinary Medicine education required choices.

The degree of success of the project can be attributed to the role of and interactions with Veterinary Medicine faculty and staff, who played an essential role in incorporating the
systems-thinking concept throughout the subject matter and making courses open to change. From a very early stage of the project, it was important that participating faculty understand the goals of the project and have a global picture as to what improvements the project was seeking to make. Systems trainers needed to work very hard and frequently with the instructors to make sure they could utilize systems thinking without consciously thinking whether they covered the eight systems-thinking techniques. In addition, the implementation of systems instruction had to be customized according to the needs of each particular course. Ongoing communication with the course instructor, the instructors interacting with the students, and ongoing modification of new materials as needed during the process of incorporating systems thinking into the curriculum were essential.

**Limitations**

There were several limitations encountered in this research. First, this initial incorporation of the systems approach into veterinary instruction at ISU was minimal. Students received only two 50-minute lectures regarding the systems-thinking approach and involving the specific scenarios presented in the assessment in the first two design experiments and an additional four lectures in the third design experiment. Instead of embedding systems thinking into an existing course for intervention, two guest lectures independent of the subject matter were given in Design Experiment 2. Incorporation of the systems approach into the instruction was modest. The reasons for this low level of instructional intervention exposure included the new instruction being developed in a relatively tight time frame, the complexity of integrating new ideas across an already densely packed syllabus, and the time needed for busy instructors to process the new ideas and fully integrate them into the curriculum.
Second, the results do not provide clear evidence of transfer of understanding or the efficacy of the instruction to new situations. In Design Experiment 1, the same swine scenario and test items were used for the instruction and the assessment’s pretest and posttests. The length of time between the three tests was short and inconsistent (25 days between pretest and posttest 1, 30 minutes between posttest 1 and posttest 2). Given that students had just received instruction on those specific items, it is not surprising that their performance improved. The improved performance could be due to memorizing correct answers by rote as opposed to a developing understanding of the systems-approach concepts. Similar to Design Experiment 1, the design in the second experiment did not allow for measuring whether learning gains transferred to contexts other than the swine and goat scenarios presented in the instruction. Nevertheless, the test results on the beef scenario in Design Experiment 3 did suggest some level of transfer.

Third, given the limited instruction, students may have been cognitively overloaded with new knowledge on dynamic systems modeling. With such a short period of intervention, students may not have always been able to understand the concepts described in the PowerPoint and Stella simulation lectures. Most students preferred step-by-step training, going through each scenario and set of diagnostic questions to confirm their selections, although the assessment was designed to determine whether students’ systems thinking ability improved due to the intervention content without providing the correct answers. Students wanted to know the correct answers as part of their reasoning about what kind of questions are systems questions and why.

Fourth, the Veterinary Medicine faculty’s low involvement in both creating case scenarios and implementing systems-thinking lectures meant that not as many instructional
materials were constructed as was planned. It is difficult for the Veterinary Medicine curriculum to consistently include systems thinking throughout the four-year program without involving faculty members teaching each year’s courses. The Veterinary Medicine curriculum has emphasized mainly the individual animal approach, and students have focused mainly on passing the Veterinary Medicine board.

**Recommendations and Implementations**

In order to understand systems thinking thoroughly, the systems approach should be introduced earlier, for instance, when students are starting the informatics section in the first year of Veterinary Medicine. Students would then expect the systems approach as part of the package to complete their Veterinary Medicine education without the psychological burden of learning material that will not be examined in the NAVLE. Besides, an overview on the first day of a course gets the most students’ attention, and everyone is on the same page. Furthermore, having more courses throughout the vet school, such as shelter, aquaculture, exotic zoo medicine, beef records, swine, goat, and poultry and including concurrent courses, provide a systems approach could be effective.

Students need to know how each part of the lecture ties into the overall system and have the math behind the systems model explained. Students especially need hands-on exercises with a variety real-life examples in the clinic, on the farm, or as part of a rotation or internship to practice systems thinking. That way, they can learn by talking to a client one on one, seeing the problems these clients are dealing with day to day and seeing all the different components that a veterinarian has to consider as part of the system. A role-playing class activity might help as well. Course handouts allow students to preview and review systems approaches, but it also would be helpful to have a place for students to have handouts and
articles or an online forum to learn systems approaches utilized for different circumstances.

Moreover, the frequency and content of systems training thinking for faculty needs to be increased. The content of the training should be focused on each of the eight skills of systems thinking with different scenarios. Scenario diversity can help faculty sense and see the patterns, links, and connections and incorporate and apply systems thinking in Veterinary Medicine. One way to help faculty to understand systems thinking is to have them break down a scenario, address the parts, and put the parts back together. It is important to clarify the goal of solving the problem of each scenario. In addition, the Stella application should be introduced to the faculty so that they can play with the application and discuss their problems with experts when making their systems models.

Asking students to specifically select systems approach questions and/or to generate system approach diagnostic questions for the assessment might reveal the nature of students’ understanding. For example, one of the questions on the swine scenario list was “Is there a parity difference in litters affected?” This is a “systems question” in that it provides information about the relationship between parity and scours. This is important because it is know that piglets from young animals (gilts) are more likely to have scouring problems. This is an intrinsic factor that is inherent to the “system” and thus cannot be changed. Confirming the role of parity in affected litters is critical in helping eliminate a “system” problem from a problem possibly attributable to other “non-systems” causes. As an output, once a new intervention is implemented, one can then evaluate the impact of such intervention by monitoring the change in parity differences between affected and non-affected litters for each intervention. This systems question was one of the factors that had significance level p < .0008 with Bonferroni adjustment. Schwartz et al. (2005) noted that research that has dealt
with new problems revealed developmental changes in problem solving. The developmental changes might increase the reliability of assessment and increase confidence that the assessments better reveal students’ understanding of application of the systems approach to veterinary health issues.

The purpose of this dissertation study was not to determine the reasons that students selected the specific non-systems diagnostic questions, believed those diagnostic questions should be given high priority, or considered them the most important questions that veterinarians should initially ask; therefore, this study did not examine each non-systems diagnostic question from the list of sub-problem scenario questions in the four main scenarios. Future research on applying a systems approach should examine reasons students select non-systems diagnostic questions they do as well as student performance on systems diagnostic questions.

For better results in future research, the following components should be considered in the study. First, the timeline for the three-year project should be set up with training while preparing for instruction in the first year and intervention for the second and third years of implementation. Evaluation should be at the end of each implementation.

Second, the specific three-year implementation agenda should be configured as follows.

1. To get the faculty’s full attention and implementation, all faculty members in the College of Veterinary Medicine should consider integrating more systems thinking into many different aspects of relevant instruction. They should be required to integrate systems thinking throughout the entire range of courses in the curriculum, not just in one or two lectures. It should be ensured that more than one or two
faculty members in any given program are involved with appropriate curriculum modifications associated with systems thinking. Shelter medicine and beef records especially should be included. Solutions employing systems thinking should consider the curriculum as a whole (Draper, 2010).

2. A meeting should be scheduled at the beginning of the project to help faculty establish a goal and timeline for the subsequent year’s instructional preparation. The following instructional materials should be included:

a. An introduction to systems thinking at the beginning of each class should be provided. A RW poll or related technologies should be utilized to ensure students are on the same page.

b. Multiple real-case scenarios should be created and posted on Blackboard for students to practice as many times as they desire. A hard-copy printout provided during the immediate learning session or later for review can serve as a memory aid (Dick & Latta, 1970).

c. An online source including tutorials, PowerPoint slides, and articles should be instituted and a VIN thread to provide a forum or CE where people can talk about how the systems approach actually was actual used and to describe its beneficial effects should be initiated.

d. Multiple scenarios should be embedded into a variety of courses in addition to helping students pass the NAVLE.

e. A number of hands-on systems-thinking exercises in the field, e.g., in clinics, rotation, or internships at FDA, FSIS, or production company quality-assurance sites, should be regularly provided. Such hands-on activities could help
students solve conceptualized dynamic systems problems from various viewpoints (Raia, 2005).

f. The math underlying the Stella systems simulation model should be explained. A rich picture of activities or a concept map, and examining behavior over time with a causal diagram, can enable students to visualize the big picture and further determine the key factors that could change situations or affect problems (Assaraf et al., 2013; Rehmann et al., 2011; Vanasupa et al., 2008).

g. A management game-playing activity in the class could help students review, resynthesize, observe, and apply biological and financial concepts and factors previously studied to a specific management problem (Bare, 1970). A course combining lectures and a computer-simulation game was shown to improve students’ achievement scores (Riess & Mischo, 2010).

h. A set of PowerPoint slides should be provided to students for reviewing how each part of the lecture ties into the overall system. Everything previously taught should be tied together at the end of the course. Students acquire knowledge from both interdisciplinary and multidisciplinary fields and gain skills from designing, problem solving, retrieving information, and identifying the relationships between the elements of the constructed product (Frank et al., 2003).

3. Faculty systems-approach training including Stella simulation systems models and creating systems diagnostic questions should be arranged each month. A detailed agenda for each training session should be provided to ensure faculty understand systems thinking and to aid in meeting the preparation timeline. In addition to
training, instructors should receive specific support and instruction regarding how systems thinking should be taught (Assaraf et al., 2013).

4. Methods for improving systems thinking by veterinarians should continue be explored. Aquaculture and exotic zoo cases should be generated for students to let them relate to a scenario not covered in the curriculum. A systems-approach conference at the College of Veterinary Medicine should be started to share and support communication with other veterinary schools both nationally and internationally.

Third, the following additional items should be addressed for support of systems thinking:

1. The nature of systems-diagnostic questions should be clarified. Some of the current diagnostic questions should be rethought to determine what kind of diagnostic assessment questions would actually reflect systems thinking and the nature of the knowledge it is intended for students to learn. How the diagnostic questions in the current scenarios reflect systems thinking should be discussed among instructors and explained to students. Instructors should understand beforehand how to apply systems thinking to problem solving and how to support students (Sweeney & Sterman, 2007). In addition, some of the current diagnostic questions that did not reflect instructional improvement in knowledge should be revised to show the relationships with others. The project developers should examine the assessments used in the studies such as Raia (2005), Frank et al. (2003), Rehmann et al. (2011), Vanasupa et al. (2008), Allen (2006), Bare (1970) which listed in the literature reviews for ideas that might be applied to assessment
in Veterinary Medicine.

2. Explicit explanations of how to use systems thinking should be provided. The instruction should be more explicit on how people using systems-thinking techniques would think differently than those using more traditional thinking. A previous research study has shown that providing scaffolds and explicit structure specifically on performance support helped students in developing higher levels of systems thinking (Assaraf et al., 2013).

   a. Students should be led to systems thinking by clarifying the goal of solving the problem of each scenario at the beginning of instruction and narrowing down the direction before providing the list of diagnostic questions. Clarification, activities, and choices of case options were found to be key factors impacting systems’ structural configurations (Frick & Koh, 2007).

   b. To make both faculty and students more familiar with the approach, a focus on applying systems thinking to everyday-life situations should be provided. The instruction should first help students determine what properties and key variables should be included in the big picture. Second, process and interconnection changes should be identified over time. Third, real-life situations should be plugged in to generate possible results according to the time of the year.

   c. In-depth guidance should be provided, allowing students to see the patterns emerging from a variety of systems-based scenarios to process the new thinking approach multiple times in a conceptual system.

   d. Instructors should explain how they thought through the case and how they may
have had to modify their thinking.

e. Scenarios should be broken down into their parts, the various resulting parts should be addressed, and then the parts should be put back together.

3. Instructors should interact with students and offer them opportunities to raise challenges when solving problems using systems-simulation models. Allowing students to see why their challenges are sometimes invalid because certain other variables should be included, and seeing how their suggestions might affect the system(s) being modeled.

a. Students should be mentored and interacted with on a regular basis to provide them instant feedback and to allow them to adjust their thinking in the right direction (Allen, 2006; Draper, 2010).

b. Students should be given feedback as well as opportunities to enable them to reason out their selections and confirm that their understanding is in the correct direction. Teacher instruction, along with feedback, could improve student learning with respect to systems thinking (Frick & Koh, 2007).

c. Instructors should help students transfer or relate to new concepts, or abandon pre-existing knowledge, by providing a variety of real-life examples, hints, and clues and allowing them to run the simulation themselves.

d. The “train the trainer” approach should be used to guide students in creating their own scenarios, asking general questions, and asking systems questions.

e. Practice opportunities should be offered by giving an assignment to work through a problem both before and after intervention.

4. On the assessments, students should be asked specifically to choose systems-
approach diagnostic questions instead of the “best” diagnostic questions, because the assessment might then better reveal the nature of students’ understanding. This should increase the reliability of assessment and increase confidence that the assessments better reveal students’ understanding of systems approach to veterinary health issues.

5. Previous systems-thinking studies for both macro and micro systems should be provided. Systems thinking has been used both in macro production systems (Bare, 1970) and micro systems such as the cardiovascular system (Hopkins et al., 1987). In addition to big-picture 10,000-meter thinking, operational thinking, feedback closed-loop thinking, scientific thinking, behavior overtime dynamic thinking, non-linear thinking, system-as-cause thinking, and reasoning, empathetic thinking should also be addressed.

6. Properties and key variables in a system should be distinguished. Recognizing the difference between properties and variables of interconnected systems could help students break down and organize direct and indirect components and use systems thinking efficiently. To reach higher level systems thinking, educators should emphasize teaching how to distinguish system properties and system variables (Hopkins et al., 1987) and identify the key variables (Rehmann et al., 2011).

Finally, further refinements should be made according to the current project to clarify the characteristics of diagnostic questions that uniquely reflect systems thinking. Diagnostic questions that do not clearly characterize systems thinking should be altered or eliminated until adequate reliability is achieved when using such questions to indicate whether or not students are using a systems-oriented approach.
Summary

In summary, this dissertation study investigated the application of a newly designed systems approach in the College of Veterinary Medicine to determine whether students’ performance on problem solving for various scenarios improved after intervention. The results supported the hypothesis that instructional intervention led to modest but statistically significant increases in students’ use of system thinking across the three experimental studies. However, the instructor indicated the need for faculty systems-approach training, whereas students tended to request hands-on practice to understand and retain systems-thinking skills.

The most significant contributions of this dissertation study are as follows. First, a new approach was embedded in a Veterinary Medicine course to help students include operation management and systems dynamic concepts into a “big picture” for problem solving and decision making. A systems trainer led a team of instructional designers and Veterinary Medicine faculty members, who cooperated with other faculty at KSU and the U of Ark to design this project. Second, the assessment design, including four scenarios and diagnostic questions from which students could choose, was a novel creation. Through creating case scenarios and diagnostic questions, as well as in modifying the intervention design and assessment of each experiment over time, the researcher gained expertise on how to support faculty members in an unfamiliar field on instructional design and assessment. All project materials have been posted on the project website (https://sites.google.com/site/foodsystemvet21/) for sustainable purpose-sharing with anyone who might wish to continue a similar approach and benefit from it.
REFERENCES


Draper, F. (2010). Teaching by wondering around: Learning about the world naturally. In J. Richmond, L. Stuntz, K. Richmond, & J. Egner (Eds.), *Tracing connections: Voices of systems thinkers* (pp. 52-64). Lebanon, NH: isee systems.


## APPENDIX A. DESIGN EXPERIMENT 1 SWINE SCENARIO

### Swine Scenario

You have been called as a new consultant for a 1,200 farrow-to-wean sow operation. They are in the middle of replacing their females (herd rollover) with a new genetic line. They were looking to improve their grow-finish performance as well as improve their overall herd health. The new genetic line of females has been arriving at the farm for the past 8 months. Currently they are concerned about the high number of scouring piglets in farrowing. What questions you need to ask the farm manager to determine why they are having the piglet scouring problem. Please select 5 of the best questions you should ask. The order of the selection is not important (i.e. no ranking needed).

| ns* | 1. What is the pH of the scours? |
| ns  | 2. What are you treating the piglets with? |
| ns  | 3. Are the piglets responding to treatment? |
| ns  | 4. What is your pre-breeding vaccination program? |
| ns  | 5. When are sows dewormed? |
| ns  | 6. What is the PRRS status of the sow herd? |
| ns  | 7. What diagnostics have been done lately? |
| ns  | 8. What are the new genetics of the sow farm? |
| ns  | 9. Where do you purchase your semen for the farm? |
| ns  | 10. How often is semen delivered to the farm? |
| ns  | 11. How often is semen tested for PRRS? |
| ns  | 12. Have you noticed any seasonality in the scours? |
| ns  | 13. Who supplies the feed to the farm? |
| ns  | 14. What are the nutrient specifications for the lactation diet? |
| ns  | 15. What disinfectant do you use? |
| s   | 16. How many pigs are scouring? |
| s   | 17. What is the average weaning weight of the pigs? |
| s   | 18. What is the average parity of the farms? |
| s   | 19. Is there a parity difference in litters affected? |
| s   | 20. Are you able to go completely all-in, all-out per farrowing room? |

Note: s represents systems questions, ns represented non-systems questions.
APPENDIX B. DESIGN EXPERIMENT 2 GOAT SCENARIO

Goat Alopecia Scenario

1. You are called to a fairly large (approximately 75 animals) commercial milking goat herd. Herd owners sell milk to a large organic cheese market. Milking /Freshing goats in the herd have a history of alopecia, which has recurred each year for the prior 5–7 years, and only occurs during the winter months (Dec–Feb). When you arrive to the site, which of the following questions are most important to begin to understand the issue? (SELECT THE 4 BEST QUESTIONS TO ASK)

<table>
<thead>
<tr>
<th></th>
<th>1. Is there an age predilection to the problem?</th>
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<tr>
<td>2</td>
<td>When the problem resolves, is that tied to freshening?</td>
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<tr>
<td></td>
<td>3. When the problem resolves, is it tied to a change in seasons?</td>
</tr>
<tr>
<td></td>
<td>4. Is there any therapy that the animals have responded to?</td>
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<tr>
<td></td>
<td>5. Is there any therapy that has been tried and not been effective?</td>
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<td></td>
<td>6. What results might be shown in a clinical exam of one or more affected animals?</td>
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<tr>
<td></td>
<td>7. What is the progression of the alopecia and grossly unaffected problems through the different groupings when doing exams of several animals in each pen in different stages of production?</td>
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<tr>
<td></td>
<td>8. What need to be considered when conducting a histopath exam for any lesions?</td>
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<tr>
<td></td>
<td>9. Would observing skin scrapings of alopecic areas microscopically help us to address the problem?</td>
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<tr>
<td></td>
<td>10. What is the nutritional status? What does the feed contain?</td>
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<tr>
<td></td>
<td>11. What is the parasite status of the herd?</td>
</tr>
<tr>
<td></td>
<td>12. What type of worming program is used?</td>
</tr>
<tr>
<td></td>
<td>13. What is parasite status of different production groups?</td>
</tr>
<tr>
<td></td>
<td>14. Are the goats genetically homogeneous or are multiple breeds represented?</td>
</tr>
<tr>
<td></td>
<td>15. What items are important in the lactation records and need to be reviewed?</td>
</tr>
<tr>
<td></td>
<td>16. Have there been any changes in stocking density in any of the pens?</td>
</tr>
</tbody>
</table>

*Note: s represents systems questions, ns represented non-systems questions.

2. After examining the goat herd discussed in Item 1 and interviewing the herd owners, you learn the following additional information. The problem does not appear to be associated with the age of the animal. The problem only occurs in the dry pen, and during the winter months. The alopecia resolves majority either with the arrival of spring or when the doe is moved to the milking pen. The dry pen is entirely indoors, and is crowded. Animals are moved to the dry pen based on the amount of elapsed time, with some attempts being made to even out seasonal breeding. Kids are born in the dry pen, and at freshening, does are moved to the milking pen, which is indoors with outdoor access.

Does are bred by being moved into the buck pen when they show signs of heat. There is some artificial lighting. Upon physical exam, one external parasite, chorioptes caprae, was found on one animal. The owner reports no signs of itchiness, though you observe some minor evidence of itchiness. Several treatments have been tried, without success. The goats are fed dried distiller’s grains and grass hay; they were switched about six months ago from a diet of alfalfa and grass hay. In the wintertime, large round bales tend to be used, with smaller square bales being used in the summer. The barn was recently remodeled, including paint being scraped and the barn repainted.
Of the facts presented in the scenario above, which are most likely to be important questions to ask in solving the problem? (SELECT THE BEST 5 RESPONSES)

<table>
<thead>
<tr>
<th>s*</th>
<th>1. Are animals moved to the dry pen based on the amount of elapsed time since prior breeding? Yes, animals are moved to the dry pen based on the amount of elapsed time since prior breeding.</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>2. Are does moved to the milking pen at freshening? Yes, does are moved to the milking pen at freshening.</td>
</tr>
<tr>
<td>ns</td>
<td>3. Are large round bales tend to be used in the wintertime, and with smaller square bales being used in the summer? Yes, large round bales tend to be used, with smaller square bales being used in the summer.</td>
</tr>
<tr>
<td>ns</td>
<td>4. Were any external parasites found on any animals? <em>Chorioptes caprae</em> was found only on one animal.</td>
</tr>
<tr>
<td>s</td>
<td>5. Does the problem only occur in the dry pen; the alopecia resolves when the doe is moved to the milking pen? Yes, the problem only occurs in the dry pen.</td>
</tr>
<tr>
<td>ns</td>
<td>6. Does the problem only occur during the winter months/ it resolves with the arrival of spring? Yes, the problem only occurs during the winter months.</td>
</tr>
<tr>
<td>s</td>
<td>7. Is the dry pen entirely indoors and crowded? Yes, the dry pen is entirely indoors, and is crowded.</td>
</tr>
<tr>
<td>ns</td>
<td>8. Have several treatments been tried, without success? Yes, several treatments have been tried but without success.</td>
</tr>
<tr>
<td>ns</td>
<td>9. Are some attempts made to even out seasonal breeding? Yes, some attempts are being made to even out seasonal breeding.</td>
</tr>
<tr>
<td>ns</td>
<td>10. Was the barn recently remodeled, including paint being scraped and the barn re-painted? Yes, the barn was recently remodeled, including paint being scraped and the barn re-painted.</td>
</tr>
<tr>
<td>ns</td>
<td>11. Are goats fed dried distiller’s grains and grass hay? Were they switched about six months ago from a diet of alfalfa and grass hay? Yes, the goats are fed dried distiller’s grains and grass hay, and they were switched about six months ago from a diet of alfalfa and grass hay.</td>
</tr>
<tr>
<td>s</td>
<td>12. Is the milking pen indoors with outdoor access? Yes, the milking pen is indoors with outdoor access. Yes, the milking pen is indoors with outdoor access.</td>
</tr>
<tr>
<td>ns</td>
<td>13. Does the owner report no signs of pruritus; you observe some minor evidence of pruritus? Yes, the owner reports no signs of itchiness, though you observe some minor evidence of itchiness.</td>
</tr>
<tr>
<td>ns</td>
<td>14. Is there some artificial lighting? Yes, there is some artificial lighting.</td>
</tr>
</tbody>
</table>

*Note: s represents systems questions, ns represented non-systems questions.
APPENDIX C. DESIGN EXPERIMENT 3 CHEMICAL HAZARD SCENARIO

1. You are a new Quality Assurance manager for a pork packing plant. Your HACCP Plan states at the “Live Animal Receiving step: Chemical hazards due to residues from antimicrobials are not reasonably likely to occur.” Producers of all loads sign a statement that recommended withdrawal times have been followed for any antimicrobial treatments. However, the USDA veterinarian “routinely” retains carcasses for chemical residue analysis, particularly from specific farms. He just retained another group of carcasses. Your previous plant never had this many problems.

You have a meeting with the USDA vet this afternoon. Pick 5 of the following questions that you **most urgently need an answer to**.

| ns   | 1. What chemicals are you testing for? |
| ns   | 2. Why was this carcass(es) selected for testing? |
| s    | 3. How does our company HACCP plan impact your decision to test? |
| ns   | 4. Hogs from certain farms are tested repeatedly. Do these pigs have specific health issues? |
| s    | 5. Is there a vaccine or control method producers are not using? If so, why? |
| ns   | 6. What are the consequences of continued violations? |
| ns   | 7. Is there an underlying disease, or ante mortem signs? |
| s    | 8. Does the rate of retentions vary over time/season? |
| s    | 9. Does the rate of retentions vary with the market price of hogs? |
| ns   | 10. Will switching producers decrease the likelihood of retentions? |
| s    | 11. Is there a geographical component to why there are a higher percentage of hogs retained for chemical residue analysis? |
| ns   | 12. Would buying animals from different breeding (or a different gene pool) decrease our likelihood of retentions? |

*Note: s represents systems questions, ns represented non-systems questions.

2. In your discussion from the last question, you learn the following from the USDA Public Health Veterinarian (PHV):

   We are looking for antimicrobial residues.
   Selection of carcasses for testing is based on:
   Clinical signs observed on ante mortem inspection.
   Observation of probable injection sites by the Food Inspectors during post mortem inspection.
   Gross lesions observed during post mortem inspection by the Food Inspectors or during veterinary disposition suggest a disease process which would likely be treated with an antimicrobial.

   The PHV (vet) states source or owner identity is usually unknown to inspection personnel at the time carcasses or animals are selected for testing. You learn the PHV feels having producers sign a statement ensuring that stated withdrawal times have been observed for any drugs or chemicals which have been administered or applied may not always be reliable in preventing violative residues.

   You, as the QA manager need to determine what steps or controls the packer can take to avoid another violative residue warning in the future. Some possibilities are listed below. **Pick the 5 most likely successful ways to address this potential food safety hazard.**
<table>
<thead>
<tr>
<th></th>
<th>1. Only buy hogs from producers who are Pork Quality Assurance (PQA) certified.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ns</td>
<td>2. Give guidance regarding circumstances which can affect excretion times for certain drugs (e.g., address debilitated animals, routes of administration/drug delivery, determination of appropriate dose, etc.).</td>
</tr>
<tr>
<td>s</td>
<td>3. Give producers an economic incentive to market residue-free animals.</td>
</tr>
<tr>
<td>ns</td>
<td>4. Have the packer do some pre-slaughter screening or routine residue testing of their own.</td>
</tr>
<tr>
<td>s</td>
<td>5. Buy hogs from different producers.</td>
</tr>
<tr>
<td>ns</td>
<td>6. Provide or encourage use of a consultant/veterinarian to examine alternatives for producers to decrease or cease usage of antimicrobials in certain situations.</td>
</tr>
<tr>
<td>ns</td>
<td>7. Produce pork for a niche market (e.g., organic pork; “drug free pork from specific pathogen free (SPF) pigs”).</td>
</tr>
<tr>
<td>ns</td>
<td>8. Tell producers to switch to a different drug.</td>
</tr>
<tr>
<td>s</td>
<td>9. Provide or encourage use of a consultant/veterinarian to look at nutrition, environmental management, source of growers/finishers.</td>
</tr>
<tr>
<td>ns</td>
<td>10. Recommend doubling the withdrawal time for the drug.</td>
</tr>
<tr>
<td>ns</td>
<td>11. Tell producers to follow the recommended dose.</td>
</tr>
</tbody>
</table>

*Note: s represents systems questions, ns represented non-systems questions.*
APPENDIX D. DESIGN EXPERIMENT 3 BEEF SCENARIO

It is September 8 (45 days after the bulls were removed) and you just finished palpating a herd of 274 crossbred cows and heifers. The cow herd is in the Midwestern US and owned by a single family. You determine that 36/274 (13.1%) of the cows are not pregnant (open). The herd is managed in 3 separate pastures with 86 head in pasture 1, 109 head in pasture 2 and 79 head in pasture 3.

Herd History
All of the bulls used passed a breeding soundness exam prior to the breeding season. The herd is bred by natural service with approximately 1 bull per group of 25 cows. Today, 249/274 (90.1%) of the cows have a BCS of 5 or greater. The owner reports that in the past he has had trouble maintaining his first calf heifers in the breeding herd. This pregnancy percentage is 4% lower than last year and 8% lower than our target of 95% bred. What questions would you like to ask the owner to determine why the herd has a low pregnancy rate?

Useful Definitions:
First calf heifer- a heifer that has calved once and may or may not be pregnant with her second calf, in this problem they will be 3 years old next spring.
BCS- Body Condition Score; a scale from 1-9 (1=thin, 5-6 optimal, 9=obese)

Please select the **10 BEST questions for identifying the major problem in this herd.**

<table>
<thead>
<tr>
<th></th>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>1. Is the pregnancy percentage the same between the pastures?</td>
<td>There were 19/86 (22.1%) open cows in Pasture 1, 10/109 (9.2%) open cows in Pasture 2, and 7/79 (8.9%) open cows in Pasture 3.</td>
</tr>
<tr>
<td>s</td>
<td>2. When do the cows normally calve and how long is the calving season? How long was the breeding season this year?</td>
<td>The calving season is typically from March 1st to May 5th. This past breeding season was from May 20th to July 25th.</td>
</tr>
<tr>
<td>ns</td>
<td>3. When are the calves weaned?</td>
<td>The calves were weaned in mid-October last year.</td>
</tr>
<tr>
<td>ns</td>
<td>4. What kind of ration is the herd fed?</td>
<td>The cows graze native grass pasture from May through November 15th. The cows then run on cornstalks until calving season with hay provided during poor weather. During calving season they are fed ground prairie hay, with a small amount of corn and protein supplement. Free choice salt and mineral are available year round.</td>
</tr>
<tr>
<td>s</td>
<td>5. The cows are in 3 pastures: what strategy is used to divide them between management groups?</td>
<td>Each pasture is filled with size and grass availability dictating the total number of cows. The mature cows tend to stay in the same pasture year after year. Replacements are divided by convenience and added to each pasture until it is filled to capacity. Factors of age, breed, and mature body weight are not considered when allocating cows to pastures.</td>
</tr>
<tr>
<td>s</td>
<td>6. What is the age profile and pregnancy distribution by age group in the herd?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Percent of Herd</th>
<th>Percent Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-Calf Heifers</td>
<td>58/274 (21.2%)</td>
<td>18/58 (31%)</td>
</tr>
<tr>
<td>Ages 4-8 yr.</td>
<td>156/274 (41.8%)</td>
<td>11/156 (7.1%)</td>
</tr>
<tr>
<td>Ages &gt; 8 yr.</td>
<td>60/274 (21.8%)</td>
<td>8/60 (13.3%)</td>
</tr>
</tbody>
</table>
7. What is the age distribution by pasture?

<table>
<thead>
<tr>
<th>Pasture</th>
<th>First-Calf Heifers</th>
<th>Ages 4-8 yr.</th>
<th>Ages &gt; 8 yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture 1</td>
<td>33/86 (38.4%)</td>
<td>36/86 (41.8%)</td>
<td>17/86 (19.8%)</td>
</tr>
<tr>
<td>Pasture 2</td>
<td>16/109 (14.7%)</td>
<td>69/109 (63.3%)</td>
<td>24/109 (22.0%)</td>
</tr>
<tr>
<td>Pasture 3</td>
<td>9/79 (11.4%)</td>
<td>51/79 (64.6%)</td>
<td>19/79 (24.0%)</td>
</tr>
</tbody>
</table>

8. Does the breeding season for the mature cows and the heifers start and end at the same time?
Yes, bulls are turned into the breeding pastures at the same time, and heifers are managed with the cows.

9. Did the body condition score differ by pasture?
In Pasture 1, 88.4% of cows were BCS 5 or >, there were 93.5% of cows > BCS 5 in Pasture 2, and in Pasture 3 89.9% of the cows were BCS 5 or greater.

10. Did the body condition score differ by age?
There were 84.5% of the first calf heifers BCS 5 or greater, 91.7% of the cows 4-8 years old were BCS 5 or greater, while 95% of the cows greater than 8 years old were BCS 5 or greater.

11. Were any bulls injured or otherwise removed from the breeding pasture during the breeding season?
Yes, one bull in Pasture 3 injured his stifle in the third week of the breeding season. He was permanently removed from breeding pasture.

12. Did the owner notice any aborted fetuses or retained placentas indicating an abortion prior to pregnancy evaluation?
No, but the cows are in a summer pasture and he only checks them once per week.

13. What is the vaccination strategy for the cow herd?
The cows are vaccinated annually with a vaccine that contains the following antigens: bovine viral diarrhea, infectious bovine rhinotracheitis, bovine respiratory syncytial virus, parainfluenza 3, leptospirosis (5 way), and campylobacter. The replacement heifers are on the same vaccination program as the cows with appropriate boosters and the addition of a Brucella abortus vaccination when they are 9 months old.

14. Is there any history of Tritrichomonas foetus in the herd or the area?
No, in fact we only purchase virgin bulls.

15. What does the calving distribution of the herd look like?
Based on your pregnancy test results, we can divide the predicted calving into 21 day intervals (or periods) and plot the percentage of the herd that we expect to calve by period. Period 1 is the start of the calving season (March 1). Below is the chart representing this data.

<table>
<thead>
<tr>
<th>Percentage of Cows Bred by 21-day Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Period</td>
</tr>
<tr>
<td>2nd Period</td>
</tr>
<tr>
<td>3rd Period</td>
</tr>
<tr>
<td>Open</td>
</tr>
</tbody>
</table>

16. Is the calving distribution different by pasture?
Calving distribution differences by pasture are described in the charts below:
17. Is the calving distribution different by age group? 
Calving distribution differences by age category are described in the charts below:

18. During palpation you suspected there was a problem with pregnancy rates and you collected blood on 5 open cows and 4 pregnant cows as they went through the chute. Would you like to evaluate viral (bovine viral diarrhea, infectious bovine rhinotracheitis) serologic titers? 
Results of viral serology listed below ordered by titer for each of the open (n=5) and pregnant (n=4) cows.

<table>
<thead>
<tr>
<th></th>
<th>BVD</th>
<th></th>
<th>IBR</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>Preg</td>
<td>Open</td>
<td>Preg</td>
<td></td>
</tr>
<tr>
<td>1:128</td>
<td>1:128</td>
<td>1:64</td>
<td>1:128</td>
<td></td>
</tr>
<tr>
<td>1:256</td>
<td>1:128</td>
<td>1:128</td>
<td>1:512</td>
<td></td>
</tr>
<tr>
<td>1:256</td>
<td>1:512</td>
<td>1:512</td>
<td>1:512</td>
<td></td>
</tr>
<tr>
<td>1:1024</td>
<td>1:1024</td>
<td>1:512</td>
<td>1:1024</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:1024</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

19. The owner is able to bring one of the bulls from Pasture 1 in for a breeding soundness examination: would you like results from a breeding soundness exam on him? The bull has a body condition score of 5 out of 9, normal locomotion, and no apparent musculoskeletal abnormalities. The semen characteristics include very good motility, 85% normal sperm morphology with the most common defects being detached heads and distal tail reflex. The testicles palpated normally and the scrotal circumference was 42 cm.

20. The owner is able to bring one of the bulls from Pasture 1 in for a breeding soundness examination: would you like results from a PCR for Tritrichomonas foetus? The test was negative.

21. Based on your questions and analysis of the available information from the last question, which of the following do you think is the major problem in this herd?
A. Infectious disease
B. Nutrition
C. Heifer management
D. Male fertility
E. Genetics

*Note: s represents systems questions, ns represented non-systems questions.*
APPENDIX E. DESIGN EXPERIMENT 1 POWERPOINT SLIDES

(Systems thinking concepts specifically in slides 18, 19, and 20, and briefly and indirectly in slides 10, 11, 16, 21, and 23–61)

VDPAM 445
Swine Topics

Part 1: Introduction

Dr. Alex Ramirez
Veterinary Diagnostic and Production Animal Medicine
Iowa State University

Introduction

• Course overview
• Swine practice
• Production systems
Course Introduction

• Focus will be:
  – Structure and function of swine practice
  – Necessary skills and approaches to problem solving
  – Rule out lists
  – Diagnosis and treatment

Course Introduction

• Schedule
  – 12 Lectures
  – 1 slide set ≠ 1 day’s lecture
• Readings
  – Merck Manual: baseline information (boards)
  – ISU-CVM Website (X)
  – WebCT – VDPAM 100S
    • Quizzes (8 quizzes with 5 questions each)
    • Only 2 of these questions will be on final exam
• Slides - WebCT
WebCT – VDPAM 100S

Instructions
Start here to better understand the expectations and most efficient way to complete the VDPAM 100S Swine Medicine Backgrounder.

Swine Production Overview
This is a broad, general overview of swine production on a global, national, and farm scale. After reviewing the content, complete the associated quiz with the same title.

Introduction to Farm Structure, Facilities, and Equipment
This is a digital tour of the most common farm designs and the equipment used to raise, treat, monitor and manage pigs. The goal of this digital tour is to familiarize you with relevant production infrastructure that you might need to identify to be effective in a veterinary role on the farm.

WebCT – VDPAM 100S

Biosecurity
Basic biosecurity is critical to disease prevention, public health, and effective management in livestock production. Biosecurity receives added attention in swine production because populations are increasing in size which increases the impact of disease introduction. Additionally, environments are becoming more controlled which offers additional opportunities to prevent disease spread. There are several sections in this module and each has an associated quiz.

Pig Flow Management
Correct management of animal groups as they move through facilities is critical to prevent overcrowding, mixing of varied health statuses, and maintaining efficient facility utilization. This section introduces some basic components of animal flow within and among facilities.

Veterinarian Safety
The contents of this section review appropriate measures to insure the safety of veterinary personnel while working in the swine farm environment.
Course Introduction

- Questions
  - E-mail: ramireza@iastate.edu

- Office: 2231 Lloyd Vet Med Center
  - Food Supply Veterinary Medicine
  - Office is always open

Quick Swine Scenario

- https://docs.google.com/spreadsheets/viewform?formkey=dEREV0w2M1U1NmZlZksotc2RGd0FoRUE6MQ

- 2 points
What should you know?

#1 thing!

- Know what you know as well as what you don’t know
- Don’t be afraid to say “I don’t know”
- But ……. always get back to them with an answer!!!
What should you be able to do?

- **Process of problem solving**
  - Identification - problems, opportunities
  - Record analysis
  - "Gumshoe" approach
  - Formulation - strategy, plan
  - Implementation - biggest challenge
  - Monitor - records, observations, questions
  - Refine

What should you be able to do?

- Be the pigs’ advocate
  - What’s best for the pigs
  - Does NOT exclude consideration of producer’s economic health

- Be the producer’s advocate
  - Avoid conflict of interest
  - “Standard of practice”
What should you be able to do?

- Assess risk
  - Risk = consequence \times probability

- Risk perception
  - Perceived risk ≠ assessed risk

---

Table 3. Ordering of perceived risks for 30 activities and technologies. The ordering is based on the geometric mean risk ratings within each group. Rank 1 represents the most risky activity or technology.

<table>
<thead>
<tr>
<th>Activity or Technology</th>
<th>League of Women</th>
<th>Active College Students</th>
<th>Club Members</th>
<th>Experts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scuba diving</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Jet skis</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Hang glider</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Alcoholic beverages</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>General (private) aviation</td>
<td>7</td>
<td>15</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Police work</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Penicillin</td>
<td>9</td>
<td>4</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Surgery</td>
<td>10</td>
<td>11</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Fire fighting</td>
<td>11</td>
<td>10</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Large construction</td>
<td>12</td>
<td>14</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Hunting</td>
<td>13</td>
<td>18</td>
<td>10</td>
<td>23</td>
</tr>
<tr>
<td>Spray cans</td>
<td>14</td>
<td>13</td>
<td>23</td>
<td>26</td>
</tr>
<tr>
<td>Mountain climbing</td>
<td>15</td>
<td>22</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>Bicycles</td>
<td>16</td>
<td>24</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Commercial aviation</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Electric power (non-machines)</td>
<td>18</td>
<td>15</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>Swimming</td>
<td>19</td>
<td>30</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Contraceptives</td>
<td>20</td>
<td>9</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>answered</td>
<td>21</td>
<td>25</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>MRI</td>
<td>22</td>
<td>17</td>
<td>24</td>
<td>27</td>
</tr>
<tr>
<td>High school and college football</td>
<td>23</td>
<td>26</td>
<td>21</td>
<td>29</td>
</tr>
<tr>
<td>Railroads</td>
<td>24</td>
<td>25</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Food preservatives</td>
<td>25</td>
<td>12</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>Food colouring</td>
<td>26</td>
<td>20</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>Personal care</td>
<td>27</td>
<td>28</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Prescription medicines</td>
<td>28</td>
<td>21</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>Home appliances</td>
<td>29</td>
<td>27</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td>Vaccinations</td>
<td>30</td>
<td>20</td>
<td>29</td>
<td>25</td>
</tr>
</tbody>
</table>

What should you be able to do?

- Understand financial terms and indicators
  - “Equity position”
  - P&L statements
  - Net worth reports
  - Cash flow

What should you be able to do?

- **Communicate**
  - Ask the right questions
  - Seek the right information
  - Listen to the client and farm personnel
    - Know when to stop talking
  - Present clearly defined recommendations
    - Short – usually 1 page max (bullet points)
  - Take time to communicate
  - Communicate with enthusiasm
    - Your advice is important to the client
Thought Organization

- SOAP
  - S = Subjective
  - O = Objective
  - A = Assessment
  - P = Plan

- DAMNIT-V
  - D = Degenerative
  - A = Anomaly
  - M = Metabolic
  - N = Neoplasia or nutrition
  - I = Inflammatory, infectious, or immune mediated
  - T = Trauma or toxicity
  - V = Vascular

Thought Organization

Five Production Input Model

1. Nutrition
2. Environment
3. Disease
4. Genetics
5. Management
Thought Organization

Five production input model

1. **Nutrition** - minimally quality control at farm level
   - Feeder adjustment, feed intake monitoring, particle size
   - DDGs, nutrient interactions

2. **Environment** - minimally, problem identification
   - Part of PQA plus

3. **Disease** - diagnosis, treatment, control
   - Veterinarian's primary responsibility

4. **Genetics** - Good luck, confusing area

5. **Management** - records and PEOPLE (quality control)
   - Husbandry practices
   - Finances, production and intervention costs

---

Fishbone (Venn) Diagram for piglet diarrhea

- Environment: Cold drafts
- Management: Cross fostering
- Genetics: Receptors
- Nutrition: Agalactia
- Disease: Sanitation
- Piglet Diarrhea
Risk Factor Analysis

- **X is associated with Y**
  - WAG or SWAG approach
  - Mathematical approach: Odds ratio (retrospective)
    - Strength and significance of association
    - From 2 by 2 table: $AD/BC = \text{Odds ratio}$

- Philosophy: recognize limitations of WAG’s

- Fact: World is becoming more mathematical
  - If you are not, you won’t be involved in making decisions in any business

---

Production System Overview

---
Basic Flow

Sow Unit → Isowean → Nursery → Feeder Pigs → Finisher 1

Sow Unit → Isowean → Nursery → Feeder Pigs → Finisher 2

Finisher 1: Fat Hogs, Fats, 220 – 290 lbs

Finisher 2: Finishers, Market Hogs, 220 – 290 lbs

Basic Flow #2

Sow Unit → Isowean → Wean-to-Finish

Sow Unit → Isowean → Wean-to-Finish

Wean-to-Finish: Fat Hogs, Fats, 220 – 290 lbs

Iowa State University College of Veterinary Medicine
Food Supply Veterinary Medicine
Three Site

Site 1

Sow Unit

Site 2

Nursery

Site 3

Finisher 1  Finisher 2

The BIG Picture

Isoweans  Weaners

Nursery 1  Nursery 2  Nursery 3  Nursery 4  Nursery 5

Feeder Pigs  Feeder Pigs

Finisher 1  Finisher 2  Finisher 1  Finisher 2  Finisher 1  Finisher 2  Finisher 1  Finisher 2

Market Pigs  Finishers  Fat hogs / Fats
The BIG Picture #2

New Two Site
(Currently the Standard)
Swine Production: Phases

- **Breeding Herd**: Produces weaned pigs
  - Wean-to-estrus: 5 days is normal (4 - 10)
  - Gestation: 115 days (3M, 3W, 3D)
  - Lactation: Variable average and range 16 – 21 days
- **Finishing Herd**: Produces market pigs or breeding herd replacements
  - Nursery: 6 – 8 weeks
  - Grow-Finish: After nursery until market usually 16 – 18 weeks
  - Wean-to-finish: 24 – 26 weeks
- **Birth to market**: $3 + 8 + 18 = 29$ weeks = 6½ months

Breeding/Gestation: Pens
Breeding/Gestation: Pens

Breeding/Gestation: Pens
Breeding/Gestation: Stalls

Breeding/Gestation: AI
Farrowing

Stalls/Crates
Farrowing

Nursery: Small Pens
Nursery: Large Pens

Finisher: Small Pens
Finisher: Large Pens

Wean-to-Finish Barns
Performance Measures: Growing Pigs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nursery</th>
<th>Finisher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start weight</td>
<td>12#</td>
<td>66#</td>
</tr>
<tr>
<td>Days in phase</td>
<td>54</td>
<td>120 (270#)</td>
</tr>
<tr>
<td>Daily gain</td>
<td>1.0</td>
<td>1.75</td>
</tr>
<tr>
<td>Daily feed</td>
<td>1.6</td>
<td>4.9</td>
</tr>
<tr>
<td>Feed:gain</td>
<td>1.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Mortality</td>
<td>&lt;2.0%</td>
<td>&lt;2.0%</td>
</tr>
<tr>
<td>Culls</td>
<td>NA</td>
<td>&lt;2.0%</td>
</tr>
<tr>
<td>Lights</td>
<td>NA</td>
<td>&lt;4.0%</td>
</tr>
</tbody>
</table>

Nutrition Overview

- **Young pigs** (<25-40 #’s) are fed complex diets
  - Porcine plasma protein
  - Dried whey, skim milk
  - Fish meal
- **Older pigs** are fed simple diets
  - Corn, soybean meal, macro minerals, trace minerals, and vitamins
- **Ad lib versus controlled intake**
- **Meal (mash) vs. pelleted form**
- **Highest component cost of production**
Facilities Overview

- **Extensive: Outdoors**
  - Pasture or dirt lots
  - Concrete lots
  - Shelter needed
  - Inexpensive, poor efficiency, high operating costs

- **Intensive: Indoors (confined)**
  - Pigs kept inside
  - Environment is controlled to a point
  - Expensive, good efficiency, low operating costs
  - Variable performance: design and stockperson

Husbandry Overview

- **Stockperson performance is key to success in any regard: Pig performance, welfare, and food safety**
  - Human performance depends on:
    - Knowledge and skills - training
    - Motivation - rewards and encouragement
    - Job design - often overlooked, stockperson is expected to compensate for poor working conditions

- **Specific tasks: must be easy and repeatable**
  - KISS approach

- **Organization of tasks: difficult part on large farms**
Food Safety/Meat Quality

- **Meat quality:** taste, color, pH, water holding capacity
  - PSS/PSE gene
  - Handling procedures: rest before slaughter
- **Antibiotic residues**
  - US: FDA
  - International: MRLs
- **Bacterial contamination**
  - On-farm versus at the slaughter plant
  - Antibiotic resistance
- **Broken needles and other foreign matter**

Welfare Issues

- **Antibiotic use is #1**
  - Growth promotion AND Prevention
- **Stalls for gestating sows currently #2**
  - Stall size (width and length) versus sow size
  - Pens: number per pen and space per pen
- **Other issues include:**
  - Farrowing crates for lactating sows
  - Castration, tail docking, ear notching
  - Transport
  - Care of disadvantaged pigs
System structure impacts cost of production

- **Extensive**: LOWER capital investment, LOWER fixed costs, LOWER efficiency, HIGHER variable costs

- **Intensive**: HIGHER capital investment, HIGHER fixed costs, HIGHER efficiency, LOWER variable costs

---

Iowa State University College of Veterinary Medicine
Food Supply Veterinary Medicine

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*Extensive production*
“How do you get paid?”

- Know producer goals
  - Profitability?
  - Market niche?
    - Taste differentiation
    - Brand name
    - Antibiotic free
  - Adding value to crop operations?
A targeted **throughput** drives most production systems
Generally measured not calculated
A number

**Efficiency measures** diagnose problems within system
Generally calculated rather than measured
Subject to definition of equation
Percentage, ratio, rate, etc.
HEALTH

18 pigs/sow/year
82% conception rate
867 pigs produced

18 pigs/sow/year
82% conception rate
286,761 pigs produced

genetics
Practical Implications

If number of pigs produced declines due to poor efficiency (such as low conception rate), sows are added to herd using additional gestation space to get back up to pigs produced target until conception rate problem is corrected.

Mortality Spiral

Short term fix to throughput

Poor health / throughput

Further deterioration of health
Practical Implications

So, if throughput from sow farm drops, pigs from another source get added at nursery phase

If throughput from nursery drops, pigs from another source get added to the group at finisher phase

Commingling

Adding sources is called “commingling”

Commingling requires matched age, matched immune status, identical PRRSV viruses (if positive), matched genetics…. a lot like organ donation!

Otherwise, commingling adds variation to production
Acknowledgements

- I would like to recognize others for their significant contributions to this presentation:
  - Dr. Brad Thacker
  - Dr. Locke Karriker
The Food Systems Practitioner of the 21st Century
Systems Thinking Skills
Part 1

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http://scott hurd.blogspot.com/

Origins of this talk

- Dep Undersecretary Food Safety USDA
- Antibiotic resistance debate
- PhD program as MSU (engineering)
- Higher Ed Challenge USDA grant
- The FUTURE – sustainable (safe) global food production
  - http://www.cast-science.org/publications/?the_direct Relationship_between_animal_health_and_food_safety_outcomes&show=product&productID=156971
What does Deputy Undersecretary do?

- Presidential appointment
- Secretary of Agriculture
- Food Safety Inspection Service
  - 1,100 veterinarians
  - 6,000 plants
  - 9 billion poultry
  - 100 million swine

Objectives

- Discuss the need
- Share some Systems Thinking skills
- Veterinary focus
WHY Systems Approach???

- WE NEED IT!!!! - sorely
- Vets are working in systems with individual animal view
- Little mistakes can go a long way
- Reductionist approach does not “work” for long term complex, dynamic, global issues
- Common language when working on a problem

What is the need?

- MUCH more interaction among animal, human, food systems – One Health
- Consolidation, Intensification, Globalization of food
- Growing food needs and quality demands
International food safety
Massive issue

September 24, 2008

Dear Mr. Secretary,

Thank you for the conversations on Monday, September 22, 2008, in which we discussed important food safety issues. I received and read the documents you sent with great interest.

The documents clearly noted that the Government of Mexico has made significant progress since the last time we spoke, and I appreciate that effort. The information also clearly pointed out that...

What is thinking?

- Constructing a mental model (play, story, scenario)
  - Simplifications
  - Use only essential information
  - "All models are wrong, some are useful" – MUST USE THEM!!!!

- Simulating
  - (role playing)
  - Evaluate cause & effect
Reductionist approach

- “We cannot use our classic reductionist scientific approach to address these challenges.
- As scientists we are trained to analyze problems. Analysis involves, taking apart the functioning whole (reduction), studying the parts, then mentally reassembling the parts to hopefully provide an understanding of the whole and how it functions”

Jay Forrester, Dean Emeritus, MIT

Reductionist – according to parts, disciplines, jobs

- University
  - Colleges
    - Departments
- Business
  - Item produced
  - Marketing
  - R&D
- Medical Profession
  - Bones
  - Soft tissue
  - Skin
New mindset for problem solving

- “We cannot solve problems using the same thinking we used when we created them”, Einstein
- “The continued search for better understanding of social and economic systems represents the next great frontier.” J Forrester 1991
- Broad systems changes require a systems approach to research, including interdisciplinary discussion among social and biophysical scientists, agricultural producers, community planners, industry experts, state and local governments, and others (USDA:NIFA, 2007)

Why needed in Food System?

- We change laws, organizational forms, policies, and personnel practices on the basis of impressions and committee meetings, usually without any dynamic analysis adequate to prevent unexpected consequences. (JW Forrester, 1991)
Systems model of CAUSAL PATHWAY resulting in automobile

INPUTS
Steel
Rubber
Plastic

PROCESSES
Parts manufacture
Assembly

OUTPUTS

e.g. 25% reduction in rubber will result in at least 25% reduction in cars or all cars with only 3 tires

Systems model of cases of prolonged illness due to resistance

INPUTS
Pathogens
Animals

PROCESSES
Farming
Harvest, Processing, Cooking

OUTPUTS = cases

Other sources
Resistant
Resistant
Resistant
Resistant
Resistant
Resistant
Resistant
Learnings from corporations

- Most difficulties are internally caused,
- The actions that people know they are taking, usually in the belief that the actions are a solution to difficulties, are often the cause of the problems being experienced.
- Dynamic feed-back structure of a social system tends to mislead people into taking ineffective and even counterproductive actions.
- People are sufficiently clear and correct about the reasons for local decision making—But, people often do not understand correctly what overall behavior will result from the complex interconnections of known local actions.
Must Start with Education

- The greatest impact of system dynamics on public understanding can be expected from pioneering projects now starting for introducing systems thinking into high school and undergraduate studies (Forrester, 1990; Forrester, 1976; Roberts, et al., 1983; Roberts, 1978; Roberts, et al., 1987).
- Traditional educational methods have tended to discourage synthesis and use of the knowledge that a student has already acquired.
- Education has taught static facts rather than dynamics of natural and social change.

References

- [http://www.nifa.usda.gov/about/white_papers/pdfs/bioeconomy_discussion_paper.pdf](http://www.nifa.usda.gov/about/white_papers/pdfs/bioeconomy_discussion_paper.pdf)
- **System Dynamics and the Lessons of 35 Years.**
  - Jay W. Forrester
    - Germeshausen Professor Emeritus
    - Sloan School of Management
    - Massachusetts Institute of Technology
- My [paper](http://www.nifa.usda.gov/about/white_papers/pdfs/bioeconomy_discussion_paper.pdf)
A Food Systems practitioner is NOT....

- One who works in the food “system”
- A computer modeler
- A mathematical geek
- A predictor of the future
- Just working on food safety issues

A Food Systems practitioner is ...

- Thinking with a special problem solving mindset
- Working in research, production, safety, policy, etc.
- “…NOT taking the straight path from A to B…” (P. Senge)
- Habitually using Systems thinking
What is thinking?

- Constructing a mental model (play, story, scenario)
  - Simplifications
  - Use only essential information
  - “All models are wrong, some are useful” – MUST USE THEM!!!!
- Simulating
  - (role playing)
  - Evaluate cause & effect

Systems thinking improves our capacity for mental modeling by:

- Paradigm (thinking skill set)
- Language (stocks and flows)
- Process (collaborative scientific inquiry)
- Technology (simulation)
  - C. Soderquist,
    (www.pontifexconsulting.com)
The Food Systems Practitioner of the 21st Century
Systems Thinking Skills
Part 2

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Systems thinking skills
(B. Richmond, iseesystems.com)

• The 30,000 foot view
  – What are important external forces or inputs? (boundary)
• System-as-cause
  – What structural relationships are involved?
• Operational thinking
  – How is this thing supposed to work? What are the cause-and-effect relationships?
• Closed loop (feedback) thinking
  – What internal factors drive or impact the input and output relationships?
• Dynamic thinking
  – What changes have or will happen as this processes continue?
• Non-linear thinking
  – How will strength of input/output relationships change over time?
• Scientific thinking
  – Show me the data and test hypotheses
• Generic thinking
  – How is this structure and functionality similar to others?
Food systems veterinary medicine

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Received 28 October 2013; Accepted 17 October 2013; First published online 29 November 2013

Abstract
The objective of this review is to suggest the use of the systems thinking framework to improve how veterinary medicine is applied to food production. It applies the eight essential skills of systems thinking to a few selected veterinary examples. Two of the skills determine how we approach or deal with a problem: (i) dynamic thinking (thinking a longer-term perspective) and (ii) the 30,000 foot view (expanding the boundary of analysis beyond the annual farm or even one crop). The other skills are (iii) representation, (iv) operational thinking, (v) closed-loop feedback, (vi) linear vs. non-linear thinking, (vii) scientific vs. systems thinking, and (viii) systemic thinking. The challenge is to adopt and apply this systems framework to veterinary medicine and food production. The result will be a rigorous new approach to solving the complex food and health problems of the 21st century.

1. The 30,000 foot view

• what are important external forces or inputs?
• Think horizontally
• e.g. corn pickers disease
• Includes boundary setting
  – (e.g. nutrition or not)
  – Makes a model “wrong”
Why is Chicago here?

Why is Chicago here?
Veterinary example

- Dairy farmer with high frequency of “odd” cow illnesses

Four Circles approach to pig health

1 – Complete circle walk through on the outside of the building/site
2 – Complete circle walk through on the inside of the building
3 – Complete circle evaluation of an individual pen
4 – Complete circle evaluation of an individual animal

Alex Ramirez DVM, Iowa State Univ
2. System-as-cause

- what structural relationships are involved?
- Would we have the same or similar problem even if a different infectious agent was involved?

Veterinary examples

- “we are not weaning enough pigs….”
- “poor conception rate for beef cows”
- Neonatal scours
- Skin lesions not “caused” by a bacteria
- “the prevalence of Salmonella at slaughter is 5x on the farm”
2. System as cause  
(Systems thinking skills)

- The power of the situation
  - (Stanford Univ prison experiment)
- “how stocks and flows are connected is often a bigger predictor of behavior than actual parameters themselves” (JK Doyle in *Tracing Connections*)

![Diagram of system as cause](image)

System as cause  
Veterinary example

- Pig *Salmonella* prevalence, on-farm (5%) vs at slaughter (40%)

![Diagram of veterinary example](image)

Hurd et al., 2002
Lairage is major source of post farm Salmonella infection
6 studies, 1 consistent message

• Studies
  – 1. Held in clean facility, no increase infection
  – 2. Postmortem comparison of finish pigs on-farm and at abattoir after lairage (5% vs 40%)
  – 3 & 4. Pigs exposed to Salmonella on floor can be positive in lymph nodes in < 2 hours, 15 minutes to fecal positive
  – 5. Lairage pen Environments highly contaminated
  – 6. Cull sow study - same

1. Lairage Study showed increased fecal isolation, farm through slaughter, regardless of lairage
Serotype varied by week of study

<table>
<thead>
<tr>
<th>Serotype</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
</tr>
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<tr>
<td>Agona</td>
<td>28</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Danaturn</td>
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<td>3</td>
<td>1</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>52</td>
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<td>3</td>
<td>4</td>
<td>3</td>
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<td></td>
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<td></td>
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<td></td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
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<td>17</td>
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<td>Typhimurium</td>
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<td></td>
<td></td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>37</td>
</tr>
<tr>
<td>Reading</td>
<td>1</td>
<td>6</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Uganda</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total typable</strong></td>
<td>49</td>
<td>24</td>
<td>18</td>
<td>12</td>
<td>15</td>
<td>39</td>
<td>9</td>
<td>36</td>
<td>20</td>
<td>22</td>
<td>244</td>
</tr>
</tbody>
</table>

2. Herds (6) depopulated in Accelerated Psuedorabies Eradication program (APEP)

Test, tag & randomly assign pigs

N=50

Farm

N=50

Abattoir & Rendering
Necropsy market hogs on farm

Other half to abattoir
~105 miles transport (C&D trailer)
~2.5 hours holding in pens
Sample collection at abattoir

No contamination from inside the plant

Stun Stick Drop

Effect of transport & holding pens
(6 APEP herds combined)

Percent pigs Salmonella positive by sample collected at farm and abattoir

Appl. Env. Micro, May 2002
### Serovar diversity
**Farm vs. Abattoir (APEP)**

<table>
<thead>
<tr>
<th>Farm #</th>
<th>Farm</th>
<th>Abattoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agn (1)</td>
<td>Agn (2)</td>
</tr>
<tr>
<td></td>
<td>Typhi_c (2)</td>
<td>Typhi_c (4)</td>
</tr>
<tr>
<td>2</td>
<td>Chk (2)</td>
<td>Chk (3)</td>
</tr>
<tr>
<td></td>
<td>Der (6)</td>
<td>Der (1)</td>
</tr>
<tr>
<td></td>
<td>Typhi_c (4)</td>
<td>Typhi_c (4)</td>
</tr>
<tr>
<td></td>
<td>Lon (1)</td>
<td>Lon (1)</td>
</tr>
<tr>
<td>3</td>
<td>Man (1)</td>
<td>Typhi_c (25)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rdg (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Der (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bov.m (1)</td>
</tr>
<tr>
<td>4</td>
<td>Der (4)</td>
<td>Der (23)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Typhi_c (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hei (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lil (1)</td>
</tr>
<tr>
<td>5</td>
<td>Hei (1)</td>
<td>Mue (22)</td>
</tr>
<tr>
<td></td>
<td>Lon (2)</td>
<td>Mue (22)</td>
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<td>Typhi_c (1)</td>
<td>Mue (22)</td>
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<td>Mue (22)</td>
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<td>Mue (22)</td>
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<td>Agn (2)</td>
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<td>Chk (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mue (1)</td>
</tr>
</tbody>
</table>

*Includes occasions of multiple serotypes from the same site.*

### 3rd & 4th Studies
**Rapid infection experiments**

- Nalidixic acid resistant *S. typhimurium*
- Shedder pigs inoculated 4 days before exposure
- Negative pigs exposed to floor for 2, 3, 6 hours
**Rapid (2hr) infection is possible!**

*(AJVR, August 2001)*

<table>
<thead>
<tr>
<th>Time Exposure</th>
<th>Lymph node</th>
<th>Sublingual lymph node</th>
<th>Oral content</th>
<th>Rectal content</th>
<th>Pig positive on any tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/5 (control)</td>
<td>0/5</td>
<td>0/5</td>
<td>0/5</td>
<td>0/5</td>
<td>0/5</td>
</tr>
<tr>
<td>2 hour exposure</td>
<td>2/10⁴</td>
<td>0/10</td>
<td>3/10</td>
<td>7/10</td>
<td>5/10</td>
</tr>
<tr>
<td>3 hour exposure</td>
<td>1/10⁵</td>
<td>0/10</td>
<td>2/10</td>
<td>3/10</td>
<td>5/10</td>
</tr>
<tr>
<td>6 hour exposure</td>
<td>1/5⁴</td>
<td>1/5⁴</td>
<td>4/5</td>
<td>2/4</td>
<td>5/5</td>
</tr>
</tbody>
</table>

**Average exposure dose 1.5 x 10⁴**

**Experimental demonstration of rapid GI tract contamination, 15-30 minutes after exposure**

**Samples positive by time after exposure to S.Typhimurium contaminated floor**

<table>
<thead>
<tr>
<th>Time to exposure</th>
<th>Ileocecal Lnm</th>
<th>Head nodes*</th>
<th>Blood</th>
<th>Ileum section</th>
<th>Cecal contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>6.7%</td>
<td>11.1%</td>
</tr>
<tr>
<td>30 min</td>
<td>9.5%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>20.6%</td>
<td>20.0%</td>
</tr>
<tr>
<td>45 min</td>
<td>6.7%</td>
<td>43.3%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>0.0%</td>
</tr>
<tr>
<td>60 min</td>
<td>6.0%</td>
<td>0.0%</td>
<td>7.1%</td>
<td>36.0%</td>
<td>13.3%</td>
</tr>
<tr>
<td>Total</td>
<td>6.6%</td>
<td>2.8%</td>
<td>3.4%</td>
<td>21.1%</td>
<td>12.6%</td>
</tr>
</tbody>
</table>

*Average 15 pigs per time period*
Implications of Rapid Infection Experiments

- Rapid infection in transport and/or holding is feasible
- Exposure dose is consistent with environmental loads in abattoirs
- GI contamination due to ingestion
- Infection due to
  - ingestion $\rightarrow$ lymph node invasion AND/OR
  - Inhalation $\rightarrow$ lymphatic capture and transport

5. Environmental study
   (2 plants, 24 loads)

3. Pigs after slaughter

2. Trailer after unloading

Serotype A
Serotype B
Serotype C

Serotype A
Serotype E
Serotype F
Pens highly contaminated

- 100% of pens were positive
  - 76% of pen samples.
  - Plant A = 62% vs. Plant B = 90%
- 44% of trailer samples
  - 71% of trailers were NOT washed
- 33% of waterer samples contaminated
- 36 different serovars isolated
- 2nd study found levels $\sim 10^4$ to $10^5$ CFU/g

Distribution of 151 unique with in group S. enterica serovars isolated from transport trailers, holding pens before pigs entered, and pigs (ileocecal lymph nodes and cecal contents) after holding.
System as cause
Veterinary example

- Two processes between farm and abattoir
  - Transportation
  - Lairage

3. Dynamic thinking

- what changes have or will happen as this issue continues?
- “ability to see and deduce behavior patterns rather than ...predict events”
- Trends
- Oscillations – e.g. the hog cycle
No system is static, but we often have to “freeze” it in time to do diagnosis

- “What is the problem TODAY?”
- How many are sick/dead?
- Prevalence rate
- Cross-sectional study

Dynamic thinking questions to ask

- What do the data show OVER TIME?
- Does this high/low exceed previous peaks or valleys (statistical process control)?
- Are other critical inputs changing?
- Think forward, what may happen?
Is this peak due to chance?

http://en.wikipedia.org/wiki/Control_chart

The Food Systems Practitioner of the 21st Century
Systems Thinking Skills
Part 3

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College of Veterinary Medicine, Veterinary Diagnostic & Production Animal Medicine
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Systems thinking skills
(B. Richmond, iseesystems.com)

- The 30,000 foot view
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  - Show me the data and test hypotheses
- Generic thinking
  - How is this structure and functionality similar to others?

4. Operational thinking

- How is this thing supposed to work?
- Function is key
- Inherent to vet med for the animal
- NOT a differential diagnosis list
4. Operational thinking (cont)

- What are the cause and effect relationships that are producing the behaviors (desirable or non-desirable)
- e.g. - breeding system to produce:
  - lactating cows for milk sale;
  - specialized purebred genetic stock
  - hybrid animals to be raised for meat.

Representation of breeding system
Operational questions to ask

- What is this systems supposed to do?
- How well is it doing it?
- Why or why not?
- NOT a differential diagnosis list!
  - Does not always address function

The language of systems

- Stocks or state variables
  - contain a quantity of units
- Flows or Processes
  - represent a change or movement from one state to another, inputs and outputs!
- Converters, parameters, coefficients
  - multiple factors that describe the flow or process
- Boundary
  - overtly set limit of analysis
“Operational” is all about change or transformation
Name the process(es)

- Susceptible to infectious
- Infected to immune
- Sick to dead
- Feed to body weight
- Live animals to carcasses, Carcasses to meat (whole cuts, trim, ground)
- Meat to human illness with foodborne pathogens
- Open to pregnant, Milking to dry
- Unvaccinated to vaccinated
- Nursing to weaned
- Uncontaminated to contaminated (e.g. food borne pathogen on a carcass)
- Tested for infection to known infected
5. Feedback loop thinking

- “Can the set of reciprocal relationships that I’ve pieced together in fact generate the behavior patterns that are being produced by the actual system?” (Richmond, Thinking in Systems)
- what factors drive or impact the input and output relationships?
Behaviors in a closed-loop

- Exponential growth curve
- Uncontrolled epidemic
- Extinction of a species
- Commodity price cycles
Infectious disease example

See Stella

6. Non-linear thinking

- How will strength of input/output relationships change over time?
- “assumption of LINEARITY means each causal factor impacts the effect by a fixed, proportional magnitude…”
- “Rather the strength of the relationship will change with the magnitude of a 3rd variable”

6. Non-linear thinking – Vet examples

- Herd immunity
- Drug admin, more is not always better
- Law of diminishing returns,
  - e.g. Tuberculosis eradication
- Bull to cow ratio
- Stocking density and infectious disease
- Others?
7. Scientific thinking

- Show me the data
- Test hypotheses
- “Has to do with quantification more than measurement...”
- “...being rigorous about testing hypotheses...”

Changes in herd seroprevalence over time (Denmark):
Abattoir parameter at 1995 level
= Effect of on-farm (pre-harvest) only

*Simulated pork attributable human cases*

Hurd et al. 2008

19% decrease, 69 cases (P>0.05)
8. Generic thinking

- How is this structure and functionality similar to others?
- Stocks, states
- Processes, flows, Inputs/outputs
- Build up, dissipation
- Positive (reinforcing) or negative (balancing) feedback loops

Does it work?
Definition of “works”

- Predict reality — NO!!!
- Give a new insight or potential solution previously unknown – Likely
- Provide a new common language for problem solving? - Yes
- Reduce intractable problems - Depends
Systems thinking skills  
(B. Richmond, ieesystems.com) 

- The 30,000 foot view 
  - what are important external forces or inputs? (boundary) 
- System-as-cause 
  - what structural relationships are involved? 
- Operational thinking 
  - how is this thing supposed to work? 
- Closed loop thinking 
  - what factors drive or impact the input and output relationships? 
- Dynamic thinking 
  - what changes have or will happen as this issue continues? 
- Non-linear thinking 
  - how will strength of input/output relationships change over time [are there lumps or bumps in the path]? 
- Scientific thinking 
  - show me the data and test hypotheses 
- Generic thinking 
  - How is this structure and functionality similar to others? 

References 

- Richmond, J ed. Tracing Connections. 
- www.iesystems.com 
- https://sites.google.com/site/foedsystemvet21/home
APPENDIX G. DESIGN EXPERIMENT 2 ADDITIONAL STATISTICAL DATA

A mixed test time (pretest vs. posttest) for 5 students. ANOVA was conducted using the SPSS GLM program on the Design Experiment 2 data.

Table G.1
**Descriptive Statistics for the Pretest and Posttest in Design Experiment 2**

<table>
<thead>
<tr>
<th>Dependent Variables</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
<th>Std. Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre%</td>
<td>37.14%</td>
<td>9.31%</td>
<td>5</td>
<td>4.16%</td>
<td>25.57%</td>
<td>48.71%</td>
</tr>
<tr>
<td>Post%</td>
<td>42.86%</td>
<td>15.97%</td>
<td>5</td>
<td>7.14%</td>
<td>23.03%</td>
<td>62.69%</td>
</tr>
</tbody>
</table>

Table G.2
**Tests of Within-Subjects Contrasts**

<table>
<thead>
<tr>
<th>Source</th>
<th>PrePost</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>PrePost</td>
<td>Linear</td>
<td>81.63</td>
<td>1</td>
<td>81.63</td>
<td>1.88</td>
<td>.24</td>
<td>.32</td>
<td>1.88</td>
<td>.187</td>
</tr>
<tr>
<td>Error(PrePost)</td>
<td>Linear</td>
<td>173.47</td>
<td>4</td>
<td>43.37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using Type I Error leve = .05
APPENDIX H. DESIGN EXPERIMENT 3 SYSTEMS THINKING
POWERPOINT SLIDES

(Systems thinking concepts specifically in slides 17-19 and
briefly in slides 10, 11, 16, 21, 23–61)

VDPAM 445
Swine Topics

Part 1: Introduction

Dr. Alex Ramirez
Veterinary Diagnostic and
Production Animal Medicine
Iowa State University

Introduction

- Course overview
- Swine practice
- Production systems
VDPAM 445
Swine Topics

Part 1: Introduction

Dr. Alex Ramirez
Veterinary Diagnostic and Production Animal Medicine
Iowa State University

Introduction

• Course overview
• Swine practice
• Production systems
Course Introduction

- Focus will be:
  - Structure and function of swine practice
  - Necessary skills and approaches to problem solving
  - Rule out lists
  - Diagnosis and treatment

Course Introduction

- **Schedule**
  - 12 Lectures
  - 1 slide set ≠ 1 day’s lecture
- **Readings**
  - Merck Manual: baseline information (boards)
  - ISU-CVM Website (X)
  - Balckboard – VDPAM 100S
    - Quizzes (7 quizzes with 5 questions each)
    - Only 2 of these questions will be on final exam
- **Slides - WebCT**
WebCT – VDPAM 100S

Course Introduction

- Questions
  - E-mail: ramireza@iastate.edu

- Office: 2231 Lloyd Vet Med Center
  - Food Supply Veterinary Medicine
  - Office is always open
Quick Swine Scenario

- [http://vrac.us2.qualtrics.com/SE/?SID=SV_ex4Q07xHuwbFlkB](http://vrac.us2.qualtrics.com/SE/?SID=SV_ex4Q07xHuwbFlkB)
- 3 points

What should you know?

**#1 thing!**
- Know what you know as well as what you don’t know
- Don’t be afraid to say “I don’t know”
- But …… always get back to them with an answer!!!
What should you be able do?

• Solve problems, create opportunities and maintain success
  – Successful clients/vets: manage all 3
  – Unsuccessful clients/vets only solve problems
    • Old “fire engine” practice

• Survival of clients
  – Growth
  – Improved Efficiency

What should you be able do?

• Process of problem solving
  – Identification - problems, opportunities
    • Record analysis
    • “Gumshoe” approach
  – Formulation - strategy, plan
  – Implementation - biggest challenge
  – Monitor - records, observations, questions
  – Refine
What should you be able to do?

- **Be the pigs’ advocate**
  - What’s best for the pigs
  - Does NOT exclude consideration of producer’s economic health

- **Be the producer’s advocate**
  - Avoid conflict of interest
  - “Standard of practice”

What should you be able to do?

- **Assess risk**
  Risk = consequence x probability

- **Risk perception**
  Perceived risk ≠ assessed risk
Table 3. Ordering of perceived risks for 30 activities and technologies. The ordering is based on the geometric mean risk estimates within each group. Rank 1 represents the most risky activity or technology.

<table>
<thead>
<tr>
<th>Activity or Technology</th>
<th>League of Women Votes</th>
<th>Active College Students</th>
<th>Club Members</th>
<th>Experts</th>
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</thead>
<tbody>
<tr>
<td>Student course</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>26</td>
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<tr>
<td>Mining activities</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Headlines</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>4</td>
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<tr>
<td>Smoking</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Alcoholic beverages</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Ground (ground)</td>
<td>7</td>
<td>15</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Police work</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Penicillin</td>
<td>9</td>
<td>4</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>Surgery</td>
<td>10</td>
<td>11</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Firefighting</td>
<td>11</td>
<td>10</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>Large construction</td>
<td>12</td>
<td>14</td>
<td>13</td>
<td>13</td>
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<tr>
<td>Hunting</td>
<td>13</td>
<td>18</td>
<td>10</td>
<td>23</td>
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<tr>
<td>Sport cars</td>
<td>14</td>
<td>11</td>
<td>23</td>
<td>26</td>
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<tr>
<td>Mountain climbing</td>
<td>15</td>
<td>22</td>
<td>12</td>
<td>29</td>
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<tr>
<td>Bicycles</td>
<td>16</td>
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<td>14</td>
<td>15</td>
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<td>Compressed air</td>
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<td>Swimming</td>
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<td>30</td>
<td>17</td>
<td>10</td>
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<tr>
<td>Contraceptives</td>
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<td>9</td>
<td>22</td>
<td>11</td>
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<td>Skating</td>
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<td>27</td>
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<tr>
<td>High school and college football</td>
<td>23</td>
<td>26</td>
<td>21</td>
<td>27</td>
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<tr>
<td>Railroads</td>
<td>24</td>
<td>23</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Food preservatives</td>
<td>25</td>
<td>12</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>Food coloring</td>
<td>26</td>
<td>20</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>Power showers</td>
<td>27</td>
<td>28</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Prescription antibiotics</td>
<td>28</td>
<td>21</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>House appliances</td>
<td>29</td>
<td>27</td>
<td>27</td>
<td>22</td>
</tr>
<tr>
<td>Vaccinations</td>
<td>30</td>
<td>29</td>
<td>29</td>
<td>25</td>
</tr>
</tbody>
</table>

Slovic, 1987

---

What should you be able to do?

- Understand financial terms and indicators
  - “Equity position”
  - P&L statements
  - Net worth reports
  - Cash flow
What should you be able to do?

- **Communicate**
  - Ask the right questions
  - Seek the right information
  - Listen to the client and farm personnel
    - Know when to stop talking
  - Present clearly defined recommendations
    - Short – usually 1 page max (bullet points)
  - Take time to communicate
  - Communicate with enthusiasm
    - Your advice is important to the client

---

**Thought Organization**

- **SOAP**
  - S = Subjective
  - O = Objective
  - A = Assessment
  - P = Plan

- **DAMNIT-V**
  - D = Degenerative
  - A = Anomaly
  - M = Metabolic
  - N = Neoplasia or nutrition
  - I = Inflammatory, infectious, or immune mediated
  - T = Trauma or toxicity
  - V = Vascular
Thought Organization

Five Production Input Model

1. Nutrition
2. Environment
3. Disease
4. Genetics
5. Management

Thought Organization

Five production input model

1. Nutrition - minimally quality control at farm level
   - Feeder adjustment, feed intake monitoring, particle size
   - DDGs, nutrient interactions
2. Environment - minimally, problem identification
   - Part of PQA plus
3. Disease - diagnosis, treatment, control
   - Veterinarian’s primary responsibility
4. Genetics - Good luck, confusing area
5. Management - records and PEOPLE (quality control)
   - Husbandry practices
   - Finances, production and intervention costs
Fishbone (Venn) Diagram for piglet diarrhea

- Environment: Cold drafts
- Management: Cross fostering
- Genetics: Receptors
- Nutrition: Agalactia
- Disease: Sanitation
- Piglet Diarrhea

Risk Factor Analysis

- **X is associated with Y**
  - WAG or SWAG approach
  - Mathematical approach: Odds ratio (retrospective)
    - Strength and significance of association
    - From 2 by 2 table: \( \frac{AD}{BC} = \text{Odds ratio} \)
- **Philosophy: recognize limitations of WAG’s**
- **Fact: World is becoming more mathematical**
  - If you are not, you won’t be involved in making decisions in any business
Production System Overview

Basic Flow

Sow Unit

Isoweans
Weaners 8 – 15 lbs

Nursery

Feeder Pigs 35 – 75 lbs

Finishers Market Hogs 220 – 290 lbs

Finisher 1

Fat Hogs
Fats 220 – 290 lbs

Finisher 2

MARKET

MARKET

MARKET
Basic Flow
# 2

Sow Unit

Isoweans

Weaners 8 – 15 lbs

Wean-to-Finish

Fat Hogs

Fats 220 – 290 lbs

MARKET

Three Site

Site 1

Sow Unit

Site 2

Nursery

Site 3

Finisher 1

Finisher 2

Iowa State University College of Veterinary Medicine
Food Supply Veterinary Medicine
New Two Site
( Currently the Standard)

Site 1

Site 2

Swine Production: Phases

- **Breeding Herd: Produces weaned pigs**
  - Wean-to-estrus: 5 days is normal (4 - 10)
  - Gestation: 115 days (3M, 3W, 3D)
  - Lactation: Variable average and range 18 – 23 days

- **Finishing Herd: Produces market pigs**
  or breeding herd replacements
  - Nursery: 6 – 8 weeks
  - Grow-Finish: After nursery until market usually 16 – 18 weeks
  - Wean-to-finish: 24 – 26 weeks

- **Birth to market**: $3 + 8 + 18 = 29$ weeks = $6\frac{1}{2}$ months
Breeding/Gestation: Pens

Breeding/Gestation: Pens
Breeding/Gestation: Pens

Breeding/Gestation: Stalls
Breeding/Gestation: AI

Farrowing
Stalls/Crates

Farrowing
Nursery: Small Pens

Nursery: Large Pens
Finisher: Small Pens

Finisher: Large Pens
# Wean-to-Finish Barns

![Image of pigs in a barn](image)

## Performance Measures: Growing Pigs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nursery</th>
<th>Finisher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start weight</td>
<td>12#</td>
<td>66#</td>
</tr>
<tr>
<td>Days in phase</td>
<td>54</td>
<td>120 (270#)</td>
</tr>
<tr>
<td>Daily gain</td>
<td>1.0</td>
<td>1.75</td>
</tr>
<tr>
<td>Daily feed</td>
<td>1.6</td>
<td>4.9</td>
</tr>
<tr>
<td>Feed:gain</td>
<td>1.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Mortality</td>
<td>&lt;2.0%</td>
<td>&lt;2.0%</td>
</tr>
<tr>
<td>Culls</td>
<td>NA</td>
<td>&lt;2.0%</td>
</tr>
<tr>
<td>Lights</td>
<td>NA</td>
<td>&lt;4.0%</td>
</tr>
</tbody>
</table>
Nutrition Overview

- Young pigs (<25-40 #'s) are fed complex diets
  - Porcine plasma protein
  - Dried whey, skim milk
  - Fish meal
- Older pigs are fed simple diets
  - Corn, soybean meal, macro minerals, trace minerals, and vitamins
- Ad lib versus controlled intake
- Meal (mash) vs. pelleted form
- Highest component cost of production

Facilities Overview

- **Extensive: Outdoors**
  - Pasture or dirt lots
  - Concrete lots
  - Shelter needed
  - Inexpensive, poor efficiency, high operating costs
- **Intensive: Indoors (confined)**
  - Pigs kept inside
  - Environment is controlled to a point
  - Expensive, good efficiency, low operating costs
  - Variable performance: design and stockperson
Husbandry Overview

- **Stockperson performance is key to success in any regard: Pig performance, welfare, and food safety**
  - Human performance depends on:
    - Knowledge and skills - training
    - Motivation - rewards and encouragement
    - Job design - often overlooked, stockperson is expected to compensate for poor working conditions

- **Specific tasks: must be easy and repeatable**
  - KISS approach

- **Organization of tasks: difficult part on large farms**

Food Safety/Meat Quality

- **Meat quality: taste, color, pH, water holding capacity**
  - PSS/PSE gene
  - Handling procedures: rest before slaughter

- **Antibiotic residues**
  - US: FDA
  - International: MRLs

- **Bacterial contamination**
  - On-farm versus at the slaughter plant
  - Antibiotic resistance

- **Broken needles and other foreign matter**
Welfare Issues

- **Stalls for gestating sows currently #1**
  - Stall size (width and length) versus sow size
  - Pens: number per pen and space per pen
- **Antibiotic use is #2**
  - Growth promotion AND Prevention
- **Other issues include:**
  - Farrowing crates for lactating sows
  - Castration, tail docking, ear notching
  - Transport
  - Care of disadvantaged pigs

System structure impacts cost of production

- **Extensive:** LOWER capital investment, LOWER fixed costs, LOWER efficiency, HIGHER variable costs
- **Intensive:** HIGHER capital investment, HIGHER fixed costs, HIGHER efficiency, LOWER variable costs
“How do you get paid?”

- Know producer goals
  - Profitability?
  - Market niche?
    - Taste differentiation
    - Brand name
    - Antibiotic free
  - Adding value to crop operations?
A targeted **throughput** drives most production systems
Generally measured not calculated
A number

**Efficiency measures** diagnose problems within system
Generally calculated rather than measured
Subject to definition of equation
Percentage, ratio, rate, etc.

18 pigs/sow/year
82% conception rate
867 pigs produced

18 pigs/sow/year
82% conception rate
286,761 pigs produced
HEALTH

Practical Implications

If number of pigs produced declines due to poor efficiency (such as low conception rate), sows are added to herd using additional gestation space to get back up to pigs produced target until conception rate problem is corrected.
Mortality Spiral

- Poor health / throughput
- Short term fix to throughput
- Further deterioration of health

Practical Implications

So, if throughput from sow farm drops, pigs from another source get added at nursery phase

If throughput from nursery drops, pigs from another source get added to the group at finisher phase
Commingling

Adding sources is called “commingling”

Commingling requires matched age, matched immune status, identical PRRSV viruses (if positive), matched genetics…. a lot like organ donation!

Otherwise, commingling adds variation to production
Acknowledgements

- I would like to recognize others for their significant contributions to this presentation:
  - Dr. Brad Thacker
  - Dr. Locke Karriker
4 Circles Evaluation

Alex Ramirez, DVM

1 – Complete circle walk through on the outside of the building/site
2 – Complete circle walk through on the inside of the building
3 – Complete circle evaluation of an individual pen
4 – Complete circle evaluation of an individual animal
1 – Complete circle walk through on the outside of the building/site
- Important to look at the entire site
- Equipment
- Biosecurity
- Site maintenance
- Idea of overall attention to detail → first impression

2 – Complete circle walk through on the inside of the building
- Walk from one end of the building to the other
- Ventilation – overall, regions
- Stocking density
- General health of ALL pigs
- Equipment
- Group's overall assessment → NOT individual pig assessment
3 – Complete circle evaluation of an individual pen
   • Individual waters and feeders
   • Different pig sizes
   • Overall pen’s attitude
   • Any signs of loose (scouring) pigs
   • Pen’s overall assessment

4 – Complete circle evaluation of an individual animal
   • Distinguish individual pig problems vs. herd problems
   • Evaluate entire pig (head to tail)
   • Select individual pigs for necropsy which represent herd’s problem
   • Herd problems are a priority, BUT we cannot ignore individual pig problems!
4 Circle’s Objectives

- Look at the whole picture first!
- Start big and then narrow your focus
  - Start large circle and keep getting smaller
  - Start broad and keep getting more specific
- Helps separate individual pig issues vs. whole herd problems
  - Both need to be addressed
  - But, priorities will be different
  - Maximize your impact
- Use information to guide you for recommendations
  - Attention to detail
  - Investment on facilities
  - True health issues vs. management
  - Help guide in prognosis (expected outcomes)
- Be systematic so you don’t forget something!
- Once mastered, it is very quick and efficient
Questions?
APPENDIX J. DESIGN EXPERIMENT 3 ASSESSMENTS

J.1 Pretest for Goat, Swine, Chemical Hazard, and Cow Scenarios

1. Please type your last name, first name.

2. Have you ever taken IE565, AER E 565, or E E 565 for Systems Engineering and Analysis, TSM 327 Animal Production Systems, VDPAM 419x Advanced Swine Production Informatics, VDPAM 445 Clinical Medicine, or VDPAM 310 Introduction to Production Medicine?
   ○ No.
   ○ Yes. Which one and what year?
   ○ Others. Please explain.

3. You are called to a fairly large (approximately 75 animals) commercial milking goat herd. Herd owners sell milk to a large organic cheese market. Milking /Freshing goats in the herd have a history of alopecia, which has recurred each year for the prior 5-7 years, and only occurs during the winter months (Dec – Feb).

When you arrive to the site, which of the following questions are most important to begin to understand the issue?

Please select the 5 best questions to ask. There are no right or wrong questions. The order of the selection is not important (i.e. no ranking needed).

☐ 1. Is there an age predilection to the problem?
☐ 2. When the problem resolves, is that tied to freshening? (S)6
☐ 3. When the problem resolves, is it tied to a change in seasons?
☐ 4. Is there any therapy that the animals have responded to?
☐ 5. Is there any therapy that has been tried and not been effective?
☐ 6. What results might be shown in a clinical exam of one or more affected animals?
☐ 7. What is the progression of the alopecia and grossly unaffected problems through the different groupings when doing exams of several animals in each pen in different stages of production? (S)
☐ 8. What need to be considered when conducting a histopath exam for any lesions?
☐ 9. Would observing skin scrapings of alopecic areas microscopically help us to address the problem?
☐ 10. What is the nutritional status? What does the feed contain?
☐ 11. What is the parasite status of the herd?
☐ 12. What type of worming program is used?
☐ 13. What is the parasite status of different production groups? (S)
☐ 14. Are the goats genetically homogeneous or are multiple breeds represented?
☐ 15. What items are important in the lactation records and need to be reviewed?
☐ 16. Have there been any changes in stocking density in any of the pens? (S)
☐ 17. On average, how long do the animals spend in each type of pen (e.g. freshen, dry, milking)? (S)

---

6 S is systems question and best questions to ask for problem solving in this scenario.
4. After examining the goat herd discussed in the last question and interviewing the herd owners, you learn the following additional information. The problem does not appear to be associated with the age of the animal. The problem only occurs in the dry pen, and during the winter months. The alopecia resolves majority either with the arrival of spring or when the doe is moved to the milking pen. The dry pen is entirely indoors, and is crowded. Animals are moved to the dry pen based on the amount of elapsed time, with some attempts being made to even out seasonal breeding. Kids are born in the dry pen, and at freshening, does are moved to the milking pen, which is indoors with outdoor access.

Does are bred by being moved into the buck pen when they show signs of heat. There is some artificial lighting. Upon physical exam, one external parasite, *chorioptes caprae*, was found on one animal. The owner reports no signs of itchiness, though you observe some minor evidence of itchiness. Several treatments have been tried, without success. The goats are fed dried distiller’s grains and grass hay; they were switched about six months ago from a diet of alfalfa and grass hay. In the wintertime, large round bales tend to be used, with smaller square bales being used in the summer. The barn was recently remodeled, including paint being scraped and the barn re-painted.

Of the facts presented in the scenario above, which are most likely to be important questions to ask in solving the problem?

Please select the 5 best questions to ask.

- 1. Are animals moved to the dry pen based on the amount of elapsed time since prior breeding? Yes, animals are moved to the dry pen based on the amount of elapsed time since prior breeding. (S)
- 2. Are does moved to the milking pen at freshening? Yes, does are moved to the milking pen at freshening. (S)
- 3. Are large round bales tend to be used in the wintertime, and with smaller square bales being used in the summer? Yes, large round bales tend to be used, with smaller square bales being used in the summer.
- 4. Were any external parasites found on any animals? *Chorioptes caprae* was found only on one animal.
- 5. Does the problem only occur in the dry pen; the alopecia resolves when the doe is moved to the milking pen? Yes, the problem only occurs in the dry pen. (S)
- 6. Does the problem only occur during the winter months/ it resolves with the arrival of spring? Yes, the problem only occurs during the winter months.
- 7. Is the dry pen entirely indoors and crowded? Yes, the dry pen is entirely indoors, and is crowded. (S)
- 8. Have several treatments been tried, without success? Yes, several treatments have been tried but without success.
- 9. Are some attempts made to even out seasonal breeding? Yes, some attempts are being made to even out seasonal breeding.
- 10. Was the barn recently remodeled, including paint being scraped and the barn re-painted? Yes, the barn was recently remodeled, including paint being scraped and the barn re-painted.
- 11. Are goats fed dried distiller’s grains and grass hay? Were they switched about six months ago from a diet of alfalfa and grass hay? Yes, the goats are fed dried distiller’s grains and grass hay, and they were switched about six months ago from a diet of alfalfa and grass hay.
- 12. Is the milking pen indoors with outdoor access? Yes, the milking pen is indoors with outdoor access? Yes, the milking pen is indoors with outdoor access. (S)
- 13. Does the owner report no signs of pruritus; you observe some minor evidence of pruritus? Yes, the owner reports no signs of itchiness, though you observe some minor evidence of itchiness.
- 14. Is there some artificial lighting? Yes, there is some artificial lighting.
5. You have been called as a new consultant for a 2,400 farrow-to-wean sow operation. They are in the middle of replacing their females (herd rollover) with a new genetic line. They were looking to improve their grow-finish performance as well as improve their overall herd health. The new genetic line of females has been arriving at the farm for the past 8 months. Currently they are concerned about the high number of scouring piglets in farrowing.

What questions you need to ask the farm manager to determine why they are having the piglet scouring problem?

Please select the 5 best questions you should ask.

- 1. Currently what is the average of percent piglets that are affected with scours? (S)
- 2. What is the pH of the scours?
- 3. What is the average weaning weight of the pigs? (S)
- 4. What are you treating the piglets with?
- 5. Are the piglets responding to treatment?
- 6. What is your pre-breeding vaccination program?
- 7. When are sows dewormed?
- 8. What is the average parity of the sows? (S)
- 9. What is the PRRS status of the sow herd?
- 10. What diagnostics have been done lately?
- 11. What are the new genetics of the sow farm?
- 12. Where do you purchase your semen for the farm?
- 13. Is there a parity difference in litters affected? (S)
- 14. How often is semen delivered to the farm?
- 15. How often is semen tested for PRRS?
- 16. Have you noticed any seasonality in the scours?
- 17. Who supplies the feed to the farm?
- 18. What are the nutrient specifications for the lactation diet?
- 19. What disinfectant do you use?
- 20. Are you able to go completely all-in, all-out per farrowing room? (S)

6. You are a new Quality Assurance manager for a pork packing plant. Your HACCP Plan states at the “Live Animal Receiving step: Chemical hazards due to residues from antimicrobials are not reasonably likely to occur.” Producers of all loads sign a statement that recommended withdrawal times have been followed for any antimicrobial treatments. However, the USDA veterinarian “routinely” retains carcasses for chemical residue analysis, particularly from specific farms. He just retained another group of carcasses. Your previous plant never had this many problems.

You have a meeting with the USDA vet this afternoon. Pick 5 of the following questions that you most urgently need an answer to.

- 1. What chemicals are you testing for?
- 2. Why was this carcass(es) selected for testing?
3. How does our company HACCP plan impact your decision to test? (S)
4. Hogs from certain farms are tested repeatedly. Do these pigs have specific health issues?
5. Is there a vaccine or control method producers are not using? If so, why? (S)
6. What are the consequences of continued violations?
7. Is there an underlying disease, or ante-mortem signs?
8. Does the rate of retentions vary over time/season? (S)
9. Does the rate of retentions vary with the market price of hogs? (S)
10. Will switching producers decrease the likelihood of retentions?
11. Is there a geographical component to why there are a higher percentage of hogs retained for chemical residue analysis? (S)
12. Would buying animals from different breeding (or a different gene pool) decrease our likelihood of retentions?

7. In your discussion from the last question, you learn the following from the USDA Public Health Veterinarian (PHV):

We are looking for antimicrobial residues. Selection of carcasses for testing is based on:
Clinical signs observed on ante-mortem inspection.
Observation of probable injection sites by the Food Inspectors during post-mortem inspection.
Gross lesions observed during post-mortem inspection by the Food Inspectors or during veterinary disposition suggest a disease process which would likely be treated with an antimicrobial.

The PHV (vet) states source or owner identity is usually unknown to inspection personnel at the time carcasses or animals are selected for testing. You learn the PHV feels having producers sign a statement ensuring that stated withdrawal times have been observed for any drugs or chemicals which have been administered or applied may not always be reliable in preventing violative residues.

You, as the QA manager need to determine what steps or controls the packer can take to avoid another violative residue warning in the future. Some possibilities are listed below. Pick the 5 most likely successful ways to address this potential food safety hazard.

1. Only buy hogs from producers who are Pork Quality Assurance (PQA) certified. (S)
2. Give guidance regarding circumstances which can affect excretion times for certain drugs (e.g., address debilitated animals, routes of administration/drug delivery, determination of appropriate dose, etc.).
3. Give producers an economic incentive to market residue-free animals. (S)
4. Have the packer do some pre-slaughter screening or routine residue testing of their own. (S)
5. Buy hogs from different producers.
6. Provide or encourage use of a consultant/veterinarian to examine alternatives for producers to decrease or cease usage of antimicrobials in certain situations. (S)
7. Produce pork for a niche market (e.g., organic pork; “drug free pork from specific pathogen free (SPF) pigs”).
8. Tell producers to switch to a different drug.
9. Provide or encourage use of a consultant/veterinarian to look at nutrition, environmental management, source of growers/finishers. (S)
10. Recommend doubling the withdrawal time for the drug.
11. Tell producers to follow the recommended dose.

8. It is September 8 (45 days after the bulls were removed) and you just finished palpating a herd of 274 crossbred cows and heifers. The cow herd is in the Midwestern US and owned by a single family. You determine that 36/274 (13.1%) of the cows are not pregnant (open). The herd is managed in 3 separate pastures with 86 head in pasture 1, 109 head in pasture 2 and 79 head in pasture 3.

Herd History
- All of the bulls used passed a breeding soundness exam prior to the breeding season.
- The herd is bred by natural service with approximately 1 bull per group of 25 cows.
- Today, 249/274 (90.1%) of the cows have a BCS of 5 or greater.
- The owner reports that in the past he has had trouble maintaining his first calf heifers in the breeding herd.
- This pregnancy percentage is 4% lower than last year and 8% lower than our target of 95% bred. What questions would you like to ask the owner to determine why the herd has a low pregnancy rate?

Useful Definitions:
First calf heifer- a heifer that has calved once and may or may not be pregnant with her second calf, in this problem they will be 3 years old next spring.
BCS- Body Condition Score; a scale from 1-9 (1=thin, 5-6 optimal, 9=obese)

Please select the 10 BEST questions for identifying the major problem in this herd.

- 1. Is the pregnancy percentage the same between the pastures? (S)
  There were 19/86 (22.1%) open cows in Pasture 1, 10/109 (9.2%) open cows in Pasture 2, and 7/79 (8.9%) open cows in Pasture 3.

- 2. When do the cows normally calve and how long is the calving season? How long was the breeding season this year? (S)
  The calving season is typically from March 1st to May 5th. This past breeding season was from May 20th to July 25th.

- 3. When are the calves weaned?
  The calves were weaned in mid-October last year.

- 4. What kind of ration is the herd fed?
  The cows graze native grass pasture from May through November 15th. The cows then run on cornstalks until calving season with hay provided during poor weather. During calving season they are fed ground prairie hay, with a small amount of corn and protein supplement. Free choice salt and mineral are available year round.

- 5. The cows are in 3 pastures: what strategy is used to divide them between management groups? (S)
  Each pasture is filled with size and grass availability dictating the total number of cows. The mature cows tend to stay in the same pasture year after year. Replacements are divided by convenience and added to each pasture until it is filled to capacity. Factors of age, breed, and mature body weight are not considered when allocating cows to pastures.
6. What is the age profile and pregnancy distribution by age group in the herd? (S)

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Percent of Herd</th>
<th>Percent Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-Calf Heifers</td>
<td>58/274 (21.2%)</td>
<td>18/58 (31%)</td>
</tr>
<tr>
<td>Ages 4-8 yr.</td>
<td>156/274 (41.8%)</td>
<td>11/156 (7.1%)</td>
</tr>
<tr>
<td>Ages &gt; 8 yr.</td>
<td>60/274 (21.8%)</td>
<td>8/60 (13.3%)</td>
</tr>
</tbody>
</table>

7. What is the age distribution by pasture? (S)

<table>
<thead>
<tr>
<th>Pasture</th>
<th>First-Calf Heifers</th>
<th>Ages 4-8 yr.</th>
<th>Ages &gt; 8 yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture 1</td>
<td>33/86 (38.4%)</td>
<td>36/86 (41.8%)</td>
<td>17/86 (19.8%)</td>
</tr>
<tr>
<td>Pasture 2</td>
<td>16/109 (14.7%)</td>
<td>69/109 (63.3%)</td>
<td>24/109 (22.0%)</td>
</tr>
<tr>
<td>Pasture 3</td>
<td>9/79 (11.4%)</td>
<td>51/79 (64.6%)</td>
<td>19/79 (24.0%)</td>
</tr>
</tbody>
</table>

8. Does the breeding season for the mature cows and the heifers start and end at the same time? (S)
Yes, bulls are turned into the breeding pastures at the same time and heifers are managed with the cows.

9. Did the body condition score differ by pasture?
In Pasture 1, 88.4% of cows were BCS 5 or >, there were 93.5% of cows > BCS 5 in Pasture 2, and in Pasture 3 89.9% of the cows were BCS 5 or greater.

10. Did the body condition score differ by age?
There were 84.5% of the first calf heifers BCS 5 or greater, 91.7% of the cows 4-8 years old were BCS 5 or greater, while 95% of the cows greater than 8 years old were BCS 5 or greater.

11. Were any bulls injured or otherwise removed from the breeding pasture during the breeding season?
Yes, one bull in Pasture 3 injured his stifle in the third week of the breeding season. He was permanently removed from breeding pasture.

12. Did the owner notice any aborted fetuses or retained placentas indicating an abortion prior to pregnancy evaluation? (S)
No, but the cows are in a summer pasture and he only checks them once per week.

13. What is the vaccination strategy for the cow herd?
The cows are vaccinated annually with a vaccine that contains the following antigens: bovine viral diarrhea, infectious bovine rhinotracheitis, bovine respiratory syncytial virus, parainfluenza 3, leptospirosis (5 way), and campylobacter. The replacement heifers are on the same vaccination program as the cows with appropriate boosters and the addition of a Brucella abortus vaccination when they are 9 months old.

14. Is there any history of Tritrichomonas foetus in the herd or the area?
No, in fact we only purchase virgin bulls.
15. What does the calving distribution of the herd look like? (S)
Based on your pregnancy test results, we can divide the predicted calving into 21 day intervals (or periods) and plot the percentage of the herd that we expect to calve by period. Period 1 is the start of the calving season (March 1). Below is the chart representing this data:

---

**Percentage of Cows Bred by 21-day Period**

<table>
<thead>
<tr>
<th>Period</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Period</td>
<td>57%</td>
</tr>
<tr>
<td>2nd Period</td>
<td>21%</td>
</tr>
<tr>
<td>3rd Period</td>
<td>9%</td>
</tr>
<tr>
<td>Open</td>
<td>13%</td>
</tr>
</tbody>
</table>

---

16. Is the calving distribution different by pasture? (S)
Calving distribution differences by pasture are described in the charts below:

---

**Percentage of Cows in Pasture 1 Bred by 21-day Period**

<table>
<thead>
<tr>
<th>Period</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Period</td>
<td>40%</td>
</tr>
<tr>
<td>2nd Period</td>
<td>30%</td>
</tr>
<tr>
<td>3rd Period</td>
<td>10%</td>
</tr>
<tr>
<td>Open</td>
<td>20%</td>
</tr>
</tbody>
</table>

**Percentage of Cows in Pasture 2 Bred by 21-day Period**

<table>
<thead>
<tr>
<th>Period</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Period</td>
<td>40%</td>
</tr>
<tr>
<td>2nd Period</td>
<td>10%</td>
</tr>
<tr>
<td>3rd Period</td>
<td>5%</td>
</tr>
<tr>
<td>Open</td>
<td>5%</td>
</tr>
</tbody>
</table>

**Percentage of Cows in Pasture 3 Bred by 21-day Period**

<table>
<thead>
<tr>
<th>Period</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Period</td>
<td>52%</td>
</tr>
<tr>
<td>2nd Period</td>
<td>18%</td>
</tr>
<tr>
<td>3rd Period</td>
<td>8%</td>
</tr>
<tr>
<td>Open</td>
<td>12%</td>
</tr>
</tbody>
</table>

---

17. Is the calving distribution different by age group? (S)
Calving distribution differences by age category are described in the charts below:

---

**Percentage of first calvingifers Bred by 21-day Period**

<table>
<thead>
<tr>
<th>Period</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Period</td>
<td>1%</td>
</tr>
<tr>
<td>2nd Period</td>
<td>10%</td>
</tr>
<tr>
<td>3rd Period</td>
<td>18%</td>
</tr>
<tr>
<td>Open</td>
<td>32%</td>
</tr>
</tbody>
</table>

**Percentage of Cows ages 4-8 years Bred by 21-day Period**

<table>
<thead>
<tr>
<th>Period</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Period</td>
<td>74%</td>
</tr>
<tr>
<td>2nd Period</td>
<td>14%</td>
</tr>
<tr>
<td>3rd Period</td>
<td>5%</td>
</tr>
<tr>
<td>Open</td>
<td>7%</td>
</tr>
</tbody>
</table>

**Percentage of Cows older than 8 years Bred by 21-day Period**

<table>
<thead>
<tr>
<th>Period</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Period</td>
<td>6%</td>
</tr>
<tr>
<td>2nd Period</td>
<td>18%</td>
</tr>
<tr>
<td>3rd Period</td>
<td>8%</td>
</tr>
<tr>
<td>Open</td>
<td>12%</td>
</tr>
</tbody>
</table>
18. During palpation you suspected there was a problem with pregnancy rates and you collected blood on 5 open cows and 4 pregnant cows as they went through the chute. Would you like to evaluate viral (bovine viral diarrhea, infectious bovine rhinotracheitis) serologic titers? 

Results of viral serology listed below ordered by titer for each of the open (n=5) and pregnant (n=4) cows.

<table>
<thead>
<tr>
<th>BVD</th>
<th>IBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>Preg</td>
</tr>
<tr>
<td>1:128</td>
<td>1:128</td>
</tr>
<tr>
<td>1:256</td>
<td>1:128</td>
</tr>
<tr>
<td>1:256</td>
<td>1:512</td>
</tr>
<tr>
<td>1:1024</td>
<td>1:1024</td>
</tr>
<tr>
<td>1:1024</td>
<td></td>
</tr>
</tbody>
</table>

19. The owner is able to bring one of the bulls from Pasture 1 in for a breeding soundness examination: would you like results from a breeding soundness exam on him?

The bull has a body condition score of 5 out of 9, normal locomotion, and no apparent musculoskeletal abnormalities. The semen characteristics include very good motility, 85% normal sperm morphology with the most common defects being detached heads and distal tail reflex. The testicles palpated normally and the scrotal circumference was 42 cm.

20. The owner is able to bring one of the bulls from Pasture 1 in for a breeding soundness examination: would you like results from a PCR for Tritrichomonas foetus?

The test was negative.

9. Based on your questions and analysis of the available information from the last question, which of the following do you think is the major problem in this herd? (C)

- A. Infectious disease
- B. Nutrition
- C. Heifer management
- D. Male fertility
- E. Genetics
J. 2 Posttest for Goat, Swine, Chemical Hazard, and Cow Scenarios

1. Please type your last name, first name.

2. You are called to a fairly large (approximately 75 animals) commercial milking goat herd. Herd owners sell milk to a large organic cheese market. Milking/Freshing goats in the herd have a history of alopecia, which has recurred each year for the prior 5-7 years, and only occurs during the winter months (Dec – Feb).

When you arrive to the site, which of the following questions are most important to begin to understand the issue?

Please select the 5 best questions to ask. There are no right or wrong questions. The order of the selection is not important (i.e. no ranking needed).

- ☐ 1. Is there an age predilection to the problem?
- ☐ 2. When the problem resolves, is that tied to freshening? (S)
- ☐ 3. When the problem resolves, is it tied to a change in seasons?
- ☐ 4. Is there any therapy that the animals have responded to?
- ☐ 5. Is there any therapy that has been tried and not been effective?
- ☐ 6. What results might be shown in a clinical exam of one or more affected animals?
- ☐ 7. What is the progression of the alopecia and grossly unaffected problems through the different groupings when doing exams of several animals in each pen in different stages of production? (S)
- ☐ 8. What need to be considered when conducting a histopath exam for any lesions?
- ☐ 9. Would observing skin scrapings of alopecic areas microscopically help us to address the problem?
- ☐ 10. What is the nutritional status? What does the feed contain?
- ☐ 11. What is the parasite status of the herd?
- ☐ 12. What type of worming program is used?
- ☐ 13. What is the parasite status of different production groups? (S)
- ☐ 14. Are the goats genetically homogeneous or are multiple breeds represented?
- ☐ 15. What items are important in the lactation records and need to be reviewed?
- ☐ 16. Have there been any changes in stocking density in any of the pens? (S)
- ☐ 17. On average, how long do the animals spend in each type of pen (e.g. freshen, dry, milking)? (S)

3. After examining the goat herd discussed in the last question and interviewing the herd owners, you learn the following additional information. The problem does not appear to be associated with the age of the animal. The problem only occurs in the dry pen, and during the winter months. The alopecia resolves majority either with the arrival of spring or when the doe is moved to the milking pen. The dry pen is entirely indoors, and is crowded. Animals are moved to the dry pen based on the amount of elapsed time, with some attempts being made to even out seasonal breeding. Kids are born in the dry pen, and at freshening, does are moved to the milking pen, which is indoors with outdoor access.

Does are bred by being moved into the buck pen when they show signs of heat. There is some artificial lighting. Upon physical exam, one external parasite, *chorioptes caprae*, was found on one animal. The owner reports no signs of itchiness, though you observe some minor evidence of itchiness. Several treatments have been tried, without success. The goats are fed dried distiller’s grains and grass hay; they were switched about six months
ago from a diet of alfalfa and grass hay. In the wintertime, large round bales tend to be used, with smaller square bales being used in the summer. The barn was recently remodeled, including paint being scraped and the barn re-painted.

Of the facts presented in the scenario above, which are most likely to be important questions to ask in solving the problem?

Please select the 5 best questions to ask.

☐ 1. Are animals moved to the dry pen based on the amount of elapsed time since prior breeding? Yes, animals are moved to the dry pen based on the amount of elapsed time since prior breeding. (S)

☐ 2. Are does moved to the milking pen at freshening? Yes, does are moved to the milking pen at freshening. (S)

☐ 3. Are large round bales tend to be used in the wintertime, and with smaller square bales being used in the summer? Yes, large round bales tend to be used, with smaller square bales being used in the summer.

☐ 4. Were any external parasites found on any animals? Chorioptes caprae was found only on one animal.

☐ 5. Does the problem only occur in the dry pen; the alopecia resolves when the doe is moved to the milking pen? Yes, the problem only occurs in the dry pen. (S)

☐ 6. Does the problem only occur during the winter months/it resolves with the arrival of spring? Yes, the problem only occurs during the winter months.

☐ 7. Is the dry pen entirely indoors and crowded? Yes, the dry pen is entirely indoors, and is crowded. (S)

☐ 8. Have several treatments been tried, without success? Yes, several treatments have been tried but without success.

☐ 9. Are some attempts made to even out seasonal breeding? Yes, some attempts are being made to even out seasonal breeding.

☐ 10. Was the barn recently remodeled, including paint being scraped and the barn re-painted? Yes, the barn was recently remodeled, including paint being scraped and the barn re-painted.

☐ 11. Are goats fed dried distiller’s grains and grass hay? Were they switched about six months ago from a diet of alfalfa and grass hay? Yes, the goats are fed dried distiller’s grains and grass hay, and they were switched about six months ago from a diet of alfalfa and grass hay.

☐ 12. Is the milking pen indoors with outdoor access? Yes, the milking pen is indoors with outdoor access? Yes, the milking pen is indoors with outdoor access. (S)

☐ 13. Does the owner report no signs of pruritus; you observe some minor evidence of pruritus? Yes, the owner reports no signs of itchiness, though you observe some minor evidence of itchiness.

☐ 14. Is there some artificial lighting? Yes, there is some artificial lighting.

4. You have been called as a new consultant for a 2,400 farrow-to-wean sow operation. They are in the middle of replacing their females (herd rollover) with a new genetic line. They were looking to improve their grow-finish performance as well as improve their overall herd health. The new genetic line of females has been arriving at the farm for the past 8 months. Currently they are concerned about the high number of scouring piglets in farrowing.

What questions you need to ask the farm manager to determine why they are having the piglet scouring problem?

Please select the 5 best questions you should ask.

☐ 1. Currently what is the average of percent piglets that are affected with scours? (S)

☐ 2. What is the pH of the scours?
3. What is the average weaning weight of the pigs? (S)
4. What are you treating the piglets with?
5. Are the piglets responding to treatment?
6. What is your pre-breeding vaccination program?
7. When are sows dewormed?
8. What is the average parity of the sows? (S)
9. What is the PRRS status of the sow herd?
10. What diagnostics have been done lately?
11. What are the new genetics of the sow farm?
12. Where do you purchase your semen for the farm?
13. Is there a parity difference in litters affected? (S)
14. How often is semen delivered to the farm?
15. How often is semen tested for PRRS?
16. Have you noticed any seasonality in the scours?
17. Who supplies the feed to the farm?
18. What are the nutrient specifications for the lactation diet?
19. What disinfectant do you use?
20. Are you able to go completely all-in, all-out per farrowing room? (S)

5. You are a new Quality Assurance manager for a pork packing plant. Your HACCP Plan states at the “Live Animal Receiving step: Chemical hazards due to residues from antimicrobials are not reasonably likely to occur.” Producers of all loads sign a statement that recommended withdrawal times have been followed for any antimicrobial treatments. However, the USDA veterinarian “routinely” retains carcasses for chemical residue analysis, particularly from specific farms. He just retained another group of carcasses. Your previous plant never had this many problems.

You have a meeting with the USDA vet this afternoon. Pick 5 of the following questions that you most urgently need an answer to.

1. What chemicals are you testing for?
2. Why was this carcass(es) selected for testing?
3. How does our company HACCP plan impact your decision to test? (S)
4. Hogs from certain farms are tested repeatedly. Do these pigs have specific health issues?
5. Is there a vaccine or control method producers are not using? If so, why? (S)
6. What are the consequences of continued violations?
7. Is there an underlying disease, or antemortem signs?
8. Does the rate of retentions vary over time/season? (S)
9. Does the rate of retentions vary with the market price of hogs? (S)
10. Will switching producers decrease the likelihood of retentions?
11. Is there a geographical component to why there are a higher percentage of hogs retained for chemical residue analysis? (S)
12. Would buying animals from different breeding (or a different gene pool) decrease our likelihood of retentions?

6. In your discussion from the last question, you learn the following from the USDA Public Health Veterinarian (PHV):

We are looking for antimicrobial residues.
Selection of carcasses for testing is based on:
Clinical signs observed on ante mortem inspection.
Observation of probable injection sites by the Food Inspectors during post mortem inspection.
Gross lesions observed during post mortem inspection by the Food Inspectors or during veterinary disposition suggest a disease process which would likely be treated with an antimicrobial.

The PHV (vet) states source or owner identity is usually unknown to inspection personnel at the time carcasses or animals are selected for testing. You learn the PHV feels having producers sign a statement ensuring that stated withdrawal times have been observed for any drugs or chemicals which have been administered or applied may not always be reliable in preventing violative residues.

You, as the QA manager need to determine what steps or controls the packer can take to avoid another violative residue warning in the future. Some possibilities are listed below. Pick the 5 most likely successful ways to address this potential food safety hazard.

- Only buy hogs from producers who are Pork Quality Assurance (PQA) certified. (S)
- Give guidance regarding circumstances which can affect excretion times for certain drugs (e.g., address debilitated animals, routes of administration/drug delivery, determination of appropriate dose, etc.).
- Give producers an economic incentive to market residue-free animals. (S)
- Have the packer do some pre-slaughter screening or routine residue testing of their own. (S)
- Buy hogs from different producers.
- Provide or encourage use of a consultant/veterinarian to examine alternatives for producers to decrease or cease usage of antimicrobials in certain situations. (S)
- Produce pork for a niche market (e.g., organic pork; “drug free pork from specific pathogen free (SPF) pigs”).
- Tell producers to switch to a different drug.
- Provide or encourage use of a consultant/veterinarian to look at nutrition, environmental management, source of growers/finishers. (S)
- Recommend doubling the withdrawal time for the drug.
- Tell producers to follow the recommended dose.

7. It is September 8 (45 days after the bulls were removed) and you just finished palpating a herd of 274 crossbred cows and heifers. The cow herd is in the Midwestern US and owned by a single family. You determine that 36/274 (13.1%) of the cows are not pregnant (open). The herd is managed in 3 separate pastures with 86 head in pasture 1, 109 head in pasture 2 and 79 head in pasture 3.

**Herd History**
- All of the bulls used passed a breeding soundness exam prior to the breeding season.
- The herd is bred by natural service with approximately 1 bull per group of 25 cows.
- Today, 249/274 (91%) of the cows have a BCS of 5 or greater.
- The owner reports that in the past he has had trouble maintaining his first calf heifers in the breeding herd.
- This pregnancy percentage is 7% lower than last year and 8% lower than our target of 95% bred.
What questions would you like to ask the owner to determine why the herd has a low pregnancy rate? Please select the 10 BEST questions for identifying the major problem in this herd.

1. Is the pregnancy percentage the same between the pastures? (S)
   - Pasture 1: 21/86 (24%) open
   - Pasture 2: 8/109 (7%) open
   - Pasture 3: 7/79 (9%) open

2. When do the cows normally calve and how long is the calving season? (S)
   - The calving season is typically from March 1st to May 1st.

3. When are the calves weaned?
   - The calves were weaned in mid-October last year.

4. What kind of ration is the herd fed?
   - The cows graze native grass pasture from May through November 15th. The cows then run on cornstalks until calving season when hay is provided during poor weather. During calving season they are fed ground prairie hay, with a small amount of corn and protein supplement. Free choice salt and mineral are available year round.

5. The cows are in 3 pastures: what strategy is used to divide them between management groups? (S)
   - Each pasture is filled with size and grass availability dictating the total number of cows. The mature cows tend to stay in the same pasture year after year. Replacements are divided by convenience and added to each pasture until it is filled to capacity. Factors of age, breed, and mature body weight are not considered when allocating cows to pastures.

6. What is the age profile and pregnancy distribution by age group in the herd? (S)
<table>
<thead>
<tr>
<th></th>
<th>Percent of Herd</th>
<th>Percent Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-Calf Heifers</td>
<td>58/274 (21.2%)</td>
<td>9/58 (15.5%)</td>
</tr>
<tr>
<td>Ages 4-8 yr.</td>
<td>156/274 (41.8%)</td>
<td>19/156 (12%)</td>
</tr>
<tr>
<td>Ages &gt; 8 yr.</td>
<td>60/274 (21.8%)</td>
<td>8/60 (13.3%)</td>
</tr>
</tbody>
</table>

7. What is the age distribution by pasture? (S)
<table>
<thead>
<tr>
<th></th>
<th>First-Calf Heifers</th>
<th>Ages 4-8 yr.</th>
<th>Ages &gt; 8 yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture 1</td>
<td>33/86 (38.4%)</td>
<td>36/86 (41.8%)</td>
<td>17/86 (19.8%)</td>
</tr>
<tr>
<td>Pasture 2</td>
<td>16/109 (14.7%)</td>
<td>69/109 (63.3%)</td>
<td>24/109 (22.0%)</td>
</tr>
<tr>
<td>Pasture 3</td>
<td>9/79 (11.4%)</td>
<td>51/79 (64.6%)</td>
<td>19/79 (24.0%)</td>
</tr>
</tbody>
</table>

8. Does the breeding season for the mature cows and the heifers start and end at the same time? (S)
   - No, the heifer breeding season starts 2 weeks prior to turning the bulls in with the mature cows.

9. Did the body condition score differ by pasture?
   - Pasture 1: 88.4% of the cows were a BCS 5 or greater.
   - Pasture 2: 93.5% of the cows were a BCS 5 or greater.
   - Pasture 3: 89.9% of the cows were a BCS 5 or greater.

10. Did the body condition score differ by age?
    - First Calf Heifers: 90.5% BCS 5 or greater
    - 4-8 year-old cows: 91.7% BCS 5 or greater
    - >8 year-old cows: 91% BCS 5 or greater

11. Were any bulls injured or otherwise removed from the breeding pasture during the breeding season?
    - Yes, one bull in Pasture
3 injured his stifle in the third week of the breeding season, and he was permanently removed from the breeding pasture.

☐ 12. Did the owner notice any aborted fetuses or retained placentas indicating an abortion prior to pregnancy evaluation? Or did you notice any indications of recent abortions (involuting uterus) when you palpated to determine pregnancy status? (S)
The owner did not notice any aborted fetuses, but the cows are in a summer pasture and he only checks them once per week. When you palpated the cows, several open cows had large, doughy uteri, and a couple had purulent material in the uterus.

☐ 13. What is the vaccination strategy for the cow herd?
The cows are vaccinated annually with a vaccine that contains the following antigens: bovine viral diarrhea, infectious bovine rhinotracheitis, bovine respiratory syncytial virus, parainfluenza 3, leptospirosis (5 way), and campylobacter. The replacement heifers are on the same vaccination program as the cows with appropriate boosters and the addition of a Brucella abortus vaccination when they are 9 months old.

☐ 14. Is there any history of Tritrichomonas foetus in the herd or the area?
No, in fact we only purchase virgin bulls.

☐ 15. What does the calving distribution of the herd look like? (S)
Based on your pregnancy test results, we can divide the predicted calving into 21 day intervals (or periods) and plot the percentage of the herd that we expect to calve by period. Period 1 is the start of the calving season (March 1). Below is the chart representing this data.

16. Is the calving distribution different by pasture? (S)
Calving distribution differences by pasture are described in the charts below:
17. Is the calving distribution different by age group? (S)
Calving distribution differences by age category are described in the charts below:

18. During palpation you suspected there was a problem with pregnancy rates and you collected blood on 5 open cows and 4 pregnant cows as they went through the chute. Would you like to evaluate viral (bovine viral diarrhea, infectious bovine rhinotracheitis) serologic titers?
Results of viral serology listed below ordered by titer for each of the open (n=5) and pregnant (n=4) cows.

<table>
<thead>
<tr>
<th>BVD</th>
<th>Open</th>
<th>Preg</th>
<th>IBR</th>
<th>Open</th>
<th>Preg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1:128</td>
<td>1:128</td>
<td>1:64</td>
<td>1:128</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1:256</td>
<td>1:128</td>
<td>1:128</td>
<td>1:512</td>
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<tr>
<td></td>
<td>1:256</td>
<td>1:512</td>
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<td></td>
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<td></td>
<td>1:1024</td>
<td>1:1024</td>
<td>1:512</td>
<td>1:1024</td>
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<tr>
<td></td>
<td>1:1024</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

19. The owner is able to bring one of the bulls from Pasture 1 in for a breeding soundness examination: would you like results from a breeding soundness exam on him?
The bull has a body condition score of 5 out of 9, normal locomotion, and no apparent musculoskeletal abnormalities. The semen characteristics include very good motility, 85% normal sperm morphology with the most common defects being detached heads and distal tail reflex. The testicles palpated normally and the scrotal circumference was 42 cm.

20. The owner is able to bring one of the bulls from Pasture 1 in for a breeding soundness examination: would you like results from a PCR for Tritrichomonas foetus?
The test was negative.

8. Based on your questions and analysis of the available information from the last question, which of the following do you think is the major problem in this herd? (A)

- A. Infectious disease
- B. Nutrition
- C. Heifer management
- D. Male fertility
- E. Genetics
To determine whether dropped out students affect students’ overall performance on problem solving, a comparison between students who completing all three tests and students who did not have any systems approach courses was made. A mixed test time (pretest vs. posttest1 vs. posttest2) between students missed at least one test. ANOVA was conducted using the SPSS GLM program on the Design Experiment 3 data.

Table K.1
Descriptive Data For Students Who Missed At Least One Test

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Error</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest percentcorr</td>
<td>25</td>
<td>22.86</td>
<td>54.29</td>
<td>40.457</td>
<td>1.518</td>
<td>7.58982</td>
</tr>
<tr>
<td>Posttest1 percentcorr</td>
<td>26</td>
<td>28.57</td>
<td>60.00</td>
<td>42.9670</td>
<td>1.516</td>
<td>7.72933</td>
</tr>
<tr>
<td>Posttest2 percentcorr</td>
<td>14</td>
<td>40.00</td>
<td>62.86</td>
<td>48.571</td>
<td>1.822</td>
<td>6.81673</td>
</tr>
</tbody>
</table>

Table K.2
Descriptive Data on the Pretest for Students that Missed At Least One Test and Students that Completed All Three Tests

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students missing at least one test</td>
<td>40.457</td>
<td>7.58982</td>
<td>25</td>
<td>1.352</td>
</tr>
<tr>
<td>Students completing all three tests</td>
<td>40.2781</td>
<td>6.56837</td>
<td>113</td>
<td>.636</td>
</tr>
<tr>
<td>Total</td>
<td>40.3106</td>
<td>6.73549</td>
<td>138</td>
<td></td>
</tr>
</tbody>
</table>

Table K.3
Levene’s Test of Equality of Error Variances on the Pretest

<table>
<thead>
<tr>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.676</td>
<td>1</td>
<td>136</td>
<td>.412</td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
Dependent Variable: prepercentcorrnew

Table K.4
Tests of Between-Subjects Effects on the Pretest

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Model</td>
<td>.656a</td>
<td>1</td>
<td>.656</td>
<td>.014</td>
<td>.905</td>
<td>.014</td>
<td>.905</td>
<td>.014</td>
</tr>
<tr>
<td>Intercept</td>
<td>133433.841</td>
<td>1</td>
<td>133433.841</td>
<td>2920.057</td>
<td>&lt;.001</td>
<td>.955</td>
<td>2920.057</td>
<td>1.000</td>
</tr>
<tr>
<td>NewAbstCode</td>
<td>.656</td>
<td>1</td>
<td>.656</td>
<td>.014</td>
<td>.905</td>
<td>.014</td>
<td>.905</td>
<td>.014</td>
</tr>
<tr>
<td>Error</td>
<td>6214.606</td>
<td>136</td>
<td>45.696</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Total</td>
<td>230457.143</td>
<td>138</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>6215.262</td>
<td>137</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dependent Variable: prepercentcorrnew
a. R Squared = .000 (Adjusted R Squared = -.007)
b. Computed using Type I Error leve= .05

Table K.5
Descriptive Data on the Posttest 1 for Students that Missed At Least One Test and Students that Completed All Three Tests

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students missing at least one test</td>
<td>42.9670</td>
<td>7.72933</td>
<td>26</td>
<td>1.437</td>
</tr>
<tr>
<td>Students completing all three tests</td>
<td>44.4248</td>
<td>7.23402</td>
<td>113</td>
<td>.689</td>
</tr>
<tr>
<td>Total</td>
<td>44.1521</td>
<td>7.32257</td>
<td>139</td>
<td></td>
</tr>
</tbody>
</table>
Table K.6  
*Levene's Test of Equality of Error Variances* on the Posttest 1

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df1</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>44.916a</td>
<td>1</td>
<td>44.916</td>
<td>.837</td>
<td>.362</td>
<td>.006</td>
<td>.837</td>
<td>.149</td>
</tr>
<tr>
<td>Intercept</td>
<td>161427.855</td>
<td>1</td>
<td>161427.855</td>
<td>3007.028</td>
<td>&lt;.001</td>
<td>.956</td>
<td>3007.028</td>
<td>1.000</td>
</tr>
<tr>
<td>Group</td>
<td>44.916</td>
<td>1</td>
<td>44.916</td>
<td>.837</td>
<td>.362</td>
<td>.006</td>
<td>.837</td>
<td>.149</td>
</tr>
<tr>
<td>Error</td>
<td>7354.644</td>
<td>137</td>
<td>53.684</td>
<td></td>
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<tr>
<td>Total</td>
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<td>139</td>
<td></td>
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<tr>
<td>Corrected Total</td>
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<td>138</td>
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</tbody>
</table>

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.


Table K.7  
*Tests of Between-Subjects Effects on the Posttest 1*

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>15.418a</td>
<td>1</td>
<td>15.418</td>
<td>.245</td>
<td>.622</td>
<td>.002</td>
<td>.245</td>
<td>.078</td>
</tr>
<tr>
<td>Intercept</td>
<td>114873.460</td>
<td>1</td>
<td>114873.460</td>
<td>1823.049</td>
<td>&lt;.001</td>
<td>.936</td>
<td>1823.049</td>
<td>1.000</td>
</tr>
<tr>
<td>NewAbstCode</td>
<td>15.418</td>
<td>1</td>
<td>15.418</td>
<td>.245</td>
<td>.622</td>
<td>.002</td>
<td>.245</td>
<td>.078</td>
</tr>
<tr>
<td>Error</td>
<td>7876.467</td>
<td>125</td>
<td>63.012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>295420.408</td>
<td>127</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>Corrected Total</td>
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</tbody>
</table>

Tests the null hypothesis that the dependent variable is equal across groups.


Table K.8  
*Descriptive Data on the Posttest 2 for Students that Missed At Least One Test and Students that Completed All Three Tests*

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students missing at least one test</td>
<td>48.5714</td>
<td>6.81673</td>
<td>14</td>
<td>2.122</td>
</tr>
<tr>
<td>Students completing all three tests</td>
<td>47.4589</td>
<td>8.05804</td>
<td>113</td>
<td>.747</td>
</tr>
<tr>
<td>Total</td>
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<td>7.91416</td>
<td>127</td>
<td></td>
</tr>
</tbody>
</table>

Table K.9  
*Levene's Test of Equality of Error Variances* on the Posttest 2

<table>
<thead>
<tr>
<th>Source</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
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<td>Corrected Model</td>
<td>.966</td>
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<td>125</td>
<td>.328</td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.


Table K.10  
*Tests of Between-Subjects Effects on the Posttest 2*

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrected Model</td>
<td>15.418a</td>
<td>1</td>
<td>15.418</td>
<td>.245</td>
<td>.622</td>
<td>.002</td>
<td>.245</td>
<td>.078</td>
</tr>
<tr>
<td>Intercept</td>
<td>114873.460</td>
<td>1</td>
<td>114873.460</td>
<td>1823.049</td>
<td>&lt;.001</td>
<td>.936</td>
<td>1823.049</td>
<td>1.000</td>
</tr>
<tr>
<td>NewAbstCode</td>
<td>15.418</td>
<td>1</td>
<td>15.418</td>
<td>.245</td>
<td>.622</td>
<td>.002</td>
<td>.245</td>
<td>.078</td>
</tr>
<tr>
<td>Error</td>
<td>7876.467</td>
<td>125</td>
<td>63.012</td>
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<td>Total</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>7891.885</td>
<td>126</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the dependent variable is equal across groups.


b. Computed using Type I Error leve = .05
APPENDIX L. DESIGN EXPERIMENT 3 COMPARISONS OF STUDENTS WITH AND WITHOUT EXTRA INTERVENTION

To determine whether more hours of systems thinking training affect students’ performance on problem solving, a comparison between students who received more hours of systems approach training before this course and students who did not have any systems approach courses was made. A mixed test time (pretest vs. posttest1 vs. posttest2) between students who took systems approach courses before this course and who did not. ANOVA was conducted using the SPSS GLM program on the Design Experiment 3 data.

Table L.1
Descriptive Data for Students in Design Experiment 3 Who Received or Did Not Receive an Extra Intervention

<table>
<thead>
<tr>
<th>Extra419/310</th>
<th>N</th>
<th>Mean</th>
<th>Std. Error</th>
<th>95% Confidence Interval Lower Bound</th>
<th>95% Confidence Interval Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>students did not take systems approach courses before</td>
<td>56</td>
<td>43.214</td>
<td>.733</td>
<td>41.761</td>
<td>44.668</td>
</tr>
<tr>
<td>students took other systems approach courses</td>
<td>53</td>
<td>45.157</td>
<td>.754</td>
<td>43.663</td>
<td>46.651</td>
</tr>
</tbody>
</table>

Table L.2
Tests of Between-Subjects Effects on the Pretest

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Powera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>102.792</td>
<td>102.792</td>
<td>3.414</td>
<td>.067</td>
<td>.031</td>
<td>3.414</td>
<td>.449</td>
</tr>
<tr>
<td>Error</td>
<td>3221.762</td>
<td>107</td>
<td>30.110</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The F tests the effect of Extra419/310. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.
a. Computed using Type I Error leve = .05

Table L.3
Descriptive Data on the Pretest, Posttest 1, Posttest2 for Students who did not take systems approach courses before and Students who did

<table>
<thead>
<tr>
<th>Extra419/310</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest% Correct</td>
<td>students did not take systems approach courses before</td>
<td>39.0816%</td>
<td>5.89600%</td>
</tr>
<tr>
<td>students took other systems approach courses</td>
<td>41.7790%</td>
<td>7.11481%</td>
<td>53</td>
</tr>
<tr>
<td>Total</td>
<td>40.3932%</td>
<td>6.62650%</td>
<td>109</td>
</tr>
<tr>
<td>Posttest1% Correct</td>
<td>students did not take systems approach courses before</td>
<td>43.2143%</td>
<td>6.60719%</td>
</tr>
<tr>
<td>students took other systems approach courses</td>
<td>46.0377%</td>
<td>7.73705%</td>
<td>53</td>
</tr>
<tr>
<td>Total</td>
<td>44.5872%</td>
<td>7.28450%</td>
<td>109</td>
</tr>
<tr>
<td>Posttest2% Correct</td>
<td>students did not take systems approach courses before</td>
<td>47.3469%</td>
<td>7.89273%</td>
</tr>
<tr>
<td>students took other systems approach courses</td>
<td>47.6550%</td>
<td>8.49367%</td>
<td>53</td>
</tr>
<tr>
<td>Total</td>
<td>47.4967%</td>
<td>8.15375%</td>
<td>109</td>
</tr>
</tbody>
</table>

Table L.4
Box’s Test of Equality of Covariance Matricesa

<table>
<thead>
<tr>
<th>Box’s M</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.172</td>
<td>.997</td>
<td>6</td>
<td>82257.354</td>
<td>.425</td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.
a. Design: Intercept + Extra419310, Within Subjects Design: Time

7 An extra intervention means that students took other systems approach courses other than this course.
Table L.5
Descriptive Data on Pretest, Posttest1 and Posttest 2 for All Participants in Design Experiment 3

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>Std. Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>40.430</td>
<td>.624</td>
<td>39.192</td>
<td>41.668</td>
</tr>
<tr>
<td>Posttest1</td>
<td>44.626</td>
<td>.688</td>
<td>43.262</td>
<td>45.990</td>
</tr>
<tr>
<td>Posttest 2</td>
<td>47.501</td>
<td>.785</td>
<td>45.945</td>
<td>49.057</td>
</tr>
</tbody>
</table>

Table L.6
Descriptive Data And Significance Level for Pairwise Comparison Among the Pretest, Posttest1, and Posttest 2 In Design Experiment 3

<table>
<thead>
<tr>
<th>(I) Time</th>
<th>(J) Time</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>95% Confidence Interval for Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>Posttest1</td>
<td>-4.196*</td>
<td>.795</td>
<td>&lt;.001</td>
<td>-6.130</td>
</tr>
<tr>
<td></td>
<td>Posttest2</td>
<td>-7.071*</td>
<td>.824</td>
<td>&lt;.001</td>
<td>-9.076</td>
</tr>
<tr>
<td>Posttest1</td>
<td>Pretest</td>
<td>4.196*</td>
<td>.795</td>
<td>&lt;.001</td>
<td>2.261</td>
</tr>
<tr>
<td></td>
<td>Posttest2</td>
<td>-2.875*</td>
<td>.798</td>
<td>.001</td>
<td>-4.816</td>
</tr>
<tr>
<td>Posttest2</td>
<td>Pretest</td>
<td>7.071*</td>
<td>.824</td>
<td>&lt;.001</td>
<td>5.066</td>
</tr>
<tr>
<td></td>
<td>Posttest1</td>
<td>2.875*</td>
<td>.798</td>
<td>.001</td>
<td>3.934</td>
</tr>
</tbody>
</table>

* The mean difference is significant at the .05 level.

Table L.7
Multivariate Tests

<table>
<thead>
<tr>
<th>Value</th>
<th>F</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Powerb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillai’s trace</td>
<td>.411</td>
<td>36.935a</td>
<td>2</td>
<td>106</td>
<td>.411</td>
<td>73.869</td>
<td>1.00</td>
</tr>
<tr>
<td>Wilks’ lambda</td>
<td>.589</td>
<td>36.935a</td>
<td>2</td>
<td>106</td>
<td>.411</td>
<td>73.869</td>
<td>1.00</td>
</tr>
<tr>
<td>Hotelling’s trace</td>
<td>.697</td>
<td>36.935a</td>
<td>2</td>
<td>106</td>
<td>.411</td>
<td>73.869</td>
<td>1.00</td>
</tr>
<tr>
<td>Roy’s largest root</td>
<td>.697</td>
<td>36.935a</td>
<td>2</td>
<td>106</td>
<td>.411</td>
<td>73.869</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Each F tests the multivariate effect of Time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Table L.8
Extra419/310 * Time

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>Std. Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>39.082</td>
<td>.871</td>
<td>37.355</td>
<td>40.808</td>
</tr>
<tr>
<td>Posttest1</td>
<td>43.214</td>
<td>.895</td>
<td>41.131</td>
<td>45.116</td>
</tr>
<tr>
<td>Posttest2</td>
<td>47.347</td>
<td>1.094</td>
<td>45.177</td>
<td>49.517</td>
</tr>
<tr>
<td>Pretest</td>
<td>41.779</td>
<td>.895</td>
<td>40.004</td>
<td>43.554</td>
</tr>
<tr>
<td>Posttest1</td>
<td>46.038</td>
<td>.986</td>
<td>44.083</td>
<td>47.992</td>
</tr>
<tr>
<td>Posttest2</td>
<td>47.655</td>
<td>1.125</td>
<td>45.425</td>
<td>49.885</td>
</tr>
</tbody>
</table>
Table L.9

**Multivariate Tests**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Value</th>
<th>F</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Powera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>.411</td>
<td>36.935a</td>
<td>2.000</td>
<td>106</td>
<td>&lt;.001</td>
<td>.411</td>
<td>73.869</td>
<td>1.000</td>
</tr>
<tr>
<td>Wilks' Lambda</td>
<td>.589</td>
<td>36.935a</td>
<td>2.000</td>
<td>106</td>
<td>&lt;.001</td>
<td>.411</td>
<td>73.869</td>
<td>1.000</td>
</tr>
<tr>
<td>Hotelling’s Trace</td>
<td>.697</td>
<td>36.935a</td>
<td>2.000</td>
<td>106</td>
<td>&lt;.001</td>
<td>.411</td>
<td>73.869</td>
<td>1.000</td>
</tr>
<tr>
<td>Roy’s Largest Root</td>
<td>.697</td>
<td>36.935a</td>
<td>2.000</td>
<td>106</td>
<td>&lt;.001</td>
<td>.411</td>
<td>73.869</td>
<td>1.000</td>
</tr>
<tr>
<td>Time *</td>
<td>.028</td>
<td>1.500b</td>
<td>2.000</td>
<td>106</td>
<td>.228</td>
<td>.028</td>
<td>3.000</td>
<td>.314</td>
</tr>
<tr>
<td>Extra</td>
<td>.972</td>
<td>1.500b</td>
<td>2.000</td>
<td>106</td>
<td>.228</td>
<td>.028</td>
<td>3.000</td>
<td>.314</td>
</tr>
<tr>
<td>419/310</td>
<td>.028</td>
<td>1.500b</td>
<td>2.000</td>
<td>106</td>
<td>.228</td>
<td>.028</td>
<td>3.000</td>
<td>.314</td>
</tr>
<tr>
<td>Roy’s Largest Root</td>
<td>.028</td>
<td>1.500b</td>
<td>2.000</td>
<td>106</td>
<td>.228</td>
<td>.028</td>
<td>3.000</td>
<td>.314</td>
</tr>
</tbody>
</table>

a. Exact statistic
b. Computed using Type I Error leve = .05
c. Design: Intercept + Extra419310

Within Subjects Design: Time

Table L.10

**Mauchly’s Test of Sphericity**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Approx. Mauchly’s W</th>
<th>Chi-Square df</th>
<th>Sig.</th>
<th>Greenhouse-Geisser Epsilon</th>
<th>Huynh-Feldt Epsilon</th>
<th>Lower-bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>.998</td>
<td>.228</td>
<td>2</td>
<td>.892</td>
<td>.998</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

Tests of Within-Subjects Effects table.

b. Design: Intercept + Extra419310

Within Subjects Design: Time

Table L.11

**Tests of Within-Subjects Effects**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Powera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sphericity Assumed</td>
<td>2754.286</td>
<td>2</td>
<td>1377.143</td>
<td>38.929</td>
<td>&lt;.001</td>
<td>.267</td>
<td>77.858</td>
<td>1.000</td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
<td>2754.286</td>
<td>1.996</td>
<td>1380.096</td>
<td>38.929</td>
<td>&lt;.001</td>
<td>.267</td>
<td>77.691</td>
<td>1.000</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
<td>2754.286</td>
<td>2.000</td>
<td>1377.143</td>
<td>38.929</td>
<td>&lt;.001</td>
<td>.267</td>
<td>77.858</td>
<td>1.000</td>
</tr>
<tr>
<td>Lower-bound</td>
<td>2754.286</td>
<td>1.000</td>
<td>2754.286</td>
<td>38.929</td>
<td>&lt;.001</td>
<td>.267</td>
<td>38.929</td>
<td>1.000</td>
</tr>
<tr>
<td>Time *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sphericity Assumed</td>
<td>109.388</td>
<td>2</td>
<td>54.694</td>
<td>1.546</td>
<td>.215</td>
<td>.014</td>
<td>3.092</td>
<td>.326</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
<td>109.388</td>
<td>2.000</td>
<td>54.694</td>
<td>1.546</td>
<td>.215</td>
<td>.014</td>
<td>3.092</td>
<td>.326</td>
</tr>
<tr>
<td>419/310</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower-bound</td>
<td>109.388</td>
<td>1.000</td>
<td>109.388</td>
<td>1.546</td>
<td>.216</td>
<td>.014</td>
<td>1.546</td>
<td>.234</td>
</tr>
<tr>
<td>Error(Time)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sphericity Assumed</td>
<td>7570.422</td>
<td>214</td>
<td>35.376</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
<td>7570.422</td>
<td>213.542</td>
<td>35.452</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huynh-Feldt</td>
<td>7570.422</td>
<td>214.000</td>
<td>35.376</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower-bound</td>
<td>7570.422</td>
<td>107.000</td>
<td>70.752</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using Type I Error leve = .05
Table L.12  
Tests of Within-Subjects Contrasts

<table>
<thead>
<tr>
<th>Source</th>
<th>Time</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Powera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Linear</td>
<td>2722.621</td>
<td>1</td>
<td>2722.621</td>
<td>73.567</td>
<td>&lt;.001</td>
<td>.407</td>
<td>73.567</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Quadratic</td>
<td>31.666</td>
<td>1</td>
<td>31.666</td>
<td>.938</td>
<td>.335</td>
<td>.009</td>
<td>.938</td>
<td>.160</td>
</tr>
<tr>
<td>Time *</td>
<td>Linear</td>
<td>77.723</td>
<td>1</td>
<td>77.723</td>
<td>2.100</td>
<td>.150</td>
<td>.019</td>
<td>2.100</td>
<td>.301</td>
</tr>
<tr>
<td>Extra 419/310 Quadratic</td>
<td>31.666</td>
<td>1</td>
<td>31.666</td>
<td>.938</td>
<td>.335</td>
<td>.009</td>
<td>.938</td>
<td>.160</td>
<td></td>
</tr>
<tr>
<td>Error(Linear)</td>
<td>3959.948</td>
<td>107</td>
<td>37.009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Quadratic</td>
<td>3610.474</td>
<td>107</td>
<td>33.743</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using Type I Error leve = .05

Table L.13  
Levene's Test of Equality of Error Variancesa

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SumPrePct</td>
<td>.606</td>
<td>1</td>
<td>107</td>
<td>.438</td>
</tr>
<tr>
<td>SumPst1Pct</td>
<td>.346</td>
<td>1</td>
<td>107</td>
<td>.557</td>
</tr>
<tr>
<td>SumPst2Pct</td>
<td>.584</td>
<td>1</td>
<td>107</td>
<td>.446</td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.  

a. Design: Intercept + Extra419310  
Within Subjects Design: Time

Table L.14  
Tests of Between-Subjects Effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Powera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>637945.073</td>
<td>1</td>
<td>637945.073</td>
<td>7062.400</td>
<td>&lt;.001</td>
<td>.985</td>
<td>7062.400</td>
<td>1.000</td>
</tr>
<tr>
<td>Extra 419/310</td>
<td>308.376</td>
<td>1</td>
<td>308.376</td>
<td>3.414</td>
<td>.067</td>
<td>.031</td>
<td>3.414</td>
<td>.449</td>
</tr>
<tr>
<td>Error</td>
<td>9665.287</td>
<td>107</td>
<td>90.330</td>
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</tr>
</tbody>
</table>

a. Computed using Type I Error leve = .05

Table L.15  
Parameter Estimates

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Parameter</th>
<th>B</th>
<th>Std. Error</th>
<th>t</th>
<th>Sig.</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>95% Confidence Interval</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Powera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest% Correct</td>
<td>Intercept</td>
<td>41.779</td>
<td>.895</td>
<td>46.672</td>
<td>&lt;.001</td>
<td>40.004</td>
<td>43.554</td>
<td>.953</td>
<td>46.672</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>[Extra419310=1]</td>
<td>.0b</td>
<td>. .</td>
<td>.</td>
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<tr>
<td>Posttest1% Correct</td>
<td>Intercept</td>
<td>46.038</td>
<td>.986</td>
<td>46.689</td>
<td>&lt;.001</td>
<td>44.083</td>
<td>47.992</td>
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<td>46.689</td>
<td>1.000</td>
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<tr>
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<td>1.376</td>
<td>-2.052</td>
<td>.043</td>
<td>-5.551</td>
<td>-0.969</td>
<td>.038</td>
<td>2.052</td>
<td>.530</td>
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<td></td>
</tr>
<tr>
<td>[Extra419310=1]</td>
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<td>. .</td>
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</tr>
<tr>
<td>Posttest2% Correct</td>
<td>Intercept</td>
<td>47.655</td>
<td>1.125</td>
<td>42.359</td>
<td>&lt;.001</td>
<td>45.425</td>
<td>49.885</td>
<td>.944</td>
<td>42.359</td>
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<tr>
<td>[Extra419310=0]</td>
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<td>1.570</td>
<td>-1.96</td>
<td>.845</td>
<td>-3.420</td>
<td>2.803</td>
<td>.000</td>
<td>.196</td>
<td>.054</td>
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<td>. .</td>
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</tr>
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</table>

a. Computed using Type I Error leve = .05  
b. This parameter is set to zero because it is redundant.
APPENDIX M. DESIGN EXPERIMENT 3 FACTOR ANALYSES OF THE SUBTEST PERCENT CORRENT WITH MAXIMUM LIKELIHOOD EXTRACTION AND VARIMAX ROTATION

Table M.1
Rotated Factor Matrix for Posttest 2 Total Percent

<table>
<thead>
<tr>
<th>Scenario Questions</th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pst2.4Chemical1CrtPct</td>
<td>.612</td>
<td>.058</td>
</tr>
<tr>
<td>Pst2.1Goat1CrtPct</td>
<td>.450</td>
<td>.300</td>
</tr>
<tr>
<td>Pst2.3SwineCrtPct</td>
<td>.241</td>
<td>.007</td>
</tr>
<tr>
<td>Pst2.6Beef1CrtPct</td>
<td>-.128</td>
<td>.584</td>
</tr>
<tr>
<td>Pst2.2Goat2CrtPct</td>
<td>.310</td>
<td>.404</td>
</tr>
<tr>
<td>Pst2.5Chemical2CrtPct</td>
<td>.150</td>
<td>.242</td>
</tr>
</tbody>
</table>

Extraction Method: Maximum Likelihood.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

Table M.2
Reliability test for 2 group factors from 6 scenario questions

<table>
<thead>
<tr>
<th>Group factor 1</th>
<th>Cronbach’s coefficient alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.397 (.454 after removing Swine scenario question)</td>
</tr>
</tbody>
</table>

| Group factor 2 | .341 |

Table M.3
Loading for each factors for posttest 2

<table>
<thead>
<tr>
<th>SQ</th>
<th>Factors total</th>
<th>Factors’ loading for Factor analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>post2 Goat1+2 (10 sq)</td>
<td>6 factors (Maximum Likelihood)</td>
<td>Factor 1: 1.13 (.995)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 2: 2.5 (.967)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 3: 1.7 (.994)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 4: 2.1 (.867)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 5: 2.7 (.789)+1.17 (.349)+1.16 (.298)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 6: 2.2 (.829)+1.2 (.274)</td>
</tr>
<tr>
<td>post2 Swine (5 sq)</td>
<td>3 factors (Principal Component)</td>
<td>Factor 1: 1.3 (.731)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 2: 8 (.685)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 3: 1 (.888)</td>
</tr>
<tr>
<td>post2 Chemical1+2 (10 sq)</td>
<td>5 factors (Maximum Likelihood)</td>
<td>Factor 1: 2.4 (.976)+2.6 (-.206)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 2: 2.1 (.999)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 3: 2.9 (.911)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 4: 1.11 (.449)+1.3 (.379)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 5: 1.8 (.481)+1.9 (.407)</td>
</tr>
<tr>
<td>post2 Beef (10 sq)</td>
<td>5 factors (Maximum Likelihood)</td>
<td>Factor 1: 1.7 (.993)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 2: 1.12 (.997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 3: 1.2 (.719)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 4: 1.17 (.689)+1.16 (.367)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Factor 5: 1.8 (.381)</td>
</tr>
</tbody>
</table>
Table M.4

*Rotated Factor Matrixa for Goat 1 & 2*

<table>
<thead>
<tr>
<th>Component</th>
<th>Factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pst2.1Goat1.13sq</td>
<td></td>
<td>.995</td>
<td>-.066</td>
<td>-.039</td>
<td>-.044</td>
<td>-.031</td>
<td>-.011</td>
</tr>
<tr>
<td>Pst2.2Goat2.5sq</td>
<td></td>
<td>.105</td>
<td>.967</td>
<td>.048</td>
<td>-.187</td>
<td>.110</td>
<td>-.063</td>
</tr>
<tr>
<td>Pst2.2Goat2.12sq</td>
<td></td>
<td>.101</td>
<td>-.226</td>
<td>.011</td>
<td>-.072</td>
<td>.084</td>
<td>-.009</td>
</tr>
<tr>
<td>Pst2.1Goat1.7sq</td>
<td></td>
<td>-.032</td>
<td>.032</td>
<td>.994</td>
<td>.026</td>
<td>-.071</td>
<td>.047</td>
</tr>
<tr>
<td>Pst2.2Goat2.1sq</td>
<td></td>
<td>-.077</td>
<td>-.019</td>
<td>.025</td>
<td>.867</td>
<td>.010</td>
<td>-.050</td>
</tr>
<tr>
<td>Pst2.2Goat2.7sq</td>
<td></td>
<td>-.158</td>
<td>-.127</td>
<td>.090</td>
<td>-.124</td>
<td>.789</td>
<td>-.073</td>
</tr>
<tr>
<td>Pst2.1Goat1.17sq</td>
<td></td>
<td>.031</td>
<td>.087</td>
<td>-.156</td>
<td>.016</td>
<td>.349</td>
<td>.067</td>
</tr>
<tr>
<td>Pst2.1Goat1.16sq</td>
<td></td>
<td>.129</td>
<td>-.075</td>
<td>.014</td>
<td>.203</td>
<td>.298</td>
<td>.092</td>
</tr>
<tr>
<td>Pst2.2Goat2.2sq</td>
<td></td>
<td>.085</td>
<td>.069</td>
<td>.001</td>
<td>.070</td>
<td>.119</td>
<td>.829</td>
</tr>
<tr>
<td>Pst2.1Goat1.2sq</td>
<td></td>
<td>-.127</td>
<td>-.132</td>
<td>.038</td>
<td>-.170</td>
<td>-.034</td>
<td>.274</td>
</tr>
</tbody>
</table>

Extraction Method: Maximum Likelihood.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 7 iterations.

Table M.5

*Rotated Component Matrixa for Swine*

<table>
<thead>
<tr>
<th>Component</th>
<th>Component</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pst2.3Swine3sq</td>
<td></td>
<td>-.782</td>
<td>.159</td>
<td>.235</td>
</tr>
<tr>
<td>Pst2.3Swine13sq</td>
<td></td>
<td>.731</td>
<td>.132</td>
<td>.297</td>
</tr>
<tr>
<td>Pst2.3Swine20sq</td>
<td></td>
<td>.264</td>
<td>-.788</td>
<td>-.182</td>
</tr>
<tr>
<td>Pst2.3Swine8sq</td>
<td></td>
<td>.286</td>
<td>.685</td>
<td>-.288</td>
</tr>
<tr>
<td>Pst2.3Swine1sq</td>
<td></td>
<td>.027</td>
<td>-.032</td>
<td>.888</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

Table M.6

*Rotated Factor Matrixa for Chemical 1 & 2*

<table>
<thead>
<tr>
<th>Component</th>
<th>Factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pst2.5Chemical2.4sq</td>
<td></td>
<td>.976</td>
<td>-.192</td>
<td>.093</td>
<td>-.011</td>
<td>.028</td>
</tr>
<tr>
<td>Pst2.5Chemical2.6sq</td>
<td></td>
<td>-.206</td>
<td>-.123</td>
<td>.080</td>
<td>.038</td>
<td>.024</td>
</tr>
<tr>
<td>Pst2.5Chemical2.1sq</td>
<td></td>
<td>-.014</td>
<td>.999</td>
<td>.031</td>
<td>.015</td>
<td>.021</td>
</tr>
<tr>
<td>Pst2.5Chemical2.9sq</td>
<td></td>
<td>-.305</td>
<td>-.112</td>
<td>.911</td>
<td>.167</td>
<td>.190</td>
</tr>
<tr>
<td>Pst2.5Chemical2.3sq</td>
<td></td>
<td>-.103</td>
<td>-.049</td>
<td>-.363</td>
<td>.097</td>
<td>.116</td>
</tr>
<tr>
<td>Pst2.4Chemical1.5sq</td>
<td></td>
<td>-.051</td>
<td>.014</td>
<td>.152</td>
<td>-.739</td>
<td>-.203</td>
</tr>
<tr>
<td>Pst2.4Chemical1.11sq</td>
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<td>-.037</td>
<td>-.051</td>
<td>.100</td>
<td>.449</td>
<td>-.004</td>
</tr>
<tr>
<td>Pst2.4Chemical1.3sq</td>
<td></td>
<td>-.136</td>
<td>.165</td>
<td>-.098</td>
<td>.379</td>
<td>-.211</td>
</tr>
<tr>
<td>Pst2.4Chemical1.8sq</td>
<td></td>
<td>-.054</td>
<td>-.044</td>
<td>.066</td>
<td>-.058</td>
<td>.481</td>
</tr>
<tr>
<td>Pst2.4Chemical1.9sq</td>
<td></td>
<td>.058</td>
<td>.094</td>
<td>-.206</td>
<td>.169</td>
<td>.407</td>
</tr>
</tbody>
</table>

Extraction Method: Maximum Likelihood.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.
Table M.7
**Rotated Factor Matrix for Beef**

<table>
<thead>
<tr>
<th></th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pst2.6Beef1.7sq</td>
<td>.993</td>
<td>-.010</td>
<td>.047</td>
<td>-.064</td>
<td>-.077</td>
</tr>
<tr>
<td>Pst2.6Beef1.12sq</td>
<td>.000</td>
<td>.997</td>
<td>.035</td>
<td>.029</td>
<td>.059</td>
</tr>
<tr>
<td>Pst2.6Beef1.2sq</td>
<td>-.123</td>
<td>-.060</td>
<td>.719</td>
<td>-.162</td>
<td>.041</td>
</tr>
<tr>
<td>Pst2.6Beef1.1sq</td>
<td>-.026</td>
<td>-.040</td>
<td>-.320</td>
<td>-.188</td>
<td>-.099</td>
</tr>
<tr>
<td>Pst2.6Beef1.15sq</td>
<td>-.155</td>
<td>-.055</td>
<td>-.301</td>
<td>.041</td>
<td>.071</td>
</tr>
<tr>
<td>Pst2.6Beef1.17sq</td>
<td>.229</td>
<td>-.193</td>
<td>-.156</td>
<td>.689</td>
<td>.177</td>
</tr>
<tr>
<td>Pst2.6Beef1.16sq</td>
<td>-.109</td>
<td>-.066</td>
<td>-.048</td>
<td>.367</td>
<td>-.034</td>
</tr>
<tr>
<td>Pst2.6Beef1.5sq</td>
<td>.031</td>
<td>-.022</td>
<td>-.084</td>
<td>-.214</td>
<td>.117</td>
</tr>
<tr>
<td>Pst2.6Beef1.6sq</td>
<td>.004</td>
<td>-.090</td>
<td>.030</td>
<td>.042</td>
<td>-.573</td>
</tr>
<tr>
<td>Pst2.6Beef1.8sq</td>
<td>-.149</td>
<td>-.118</td>
<td>.287</td>
<td>-.002</td>
<td>.381</td>
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</tbody>
</table>

Extraction method: maximum likelihood; Rotation method: varimax with Kaiser normalization.

Table M.8
**Repeated Measures ANOVA for Each Factor for the Pre-Pst1-Pst2 Tests w/ Bonferroni Adjustment**

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Pre Mean</th>
<th>Pre Std. Dev</th>
<th>Post1 Mean</th>
<th>Post1 Std. Dev</th>
<th>Post2 Mean</th>
<th>Post2 Std. Dev</th>
<th>Significance Level</th>
<th>Bf = Bonferroni adjustment</th>
<th>p &lt; .0008</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1SC1Total %</td>
<td>109</td>
<td>26.61a</td>
<td>29.60a</td>
<td>34.13</td>
<td></td>
<td></td>
<td></td>
<td>&lt;.001**</td>
<td>Bf</td>
<td></td>
</tr>
<tr>
<td>Factor1</td>
<td></td>
<td>9.32</td>
<td>11.09</td>
<td>12.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.89</td>
<td>1.06</td>
<td>1.16</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>G2C2BTotal %</td>
<td>109</td>
<td>26.61a</td>
<td>29.60a</td>
<td>34.13a</td>
<td></td>
<td></td>
<td></td>
<td>&lt;.001**</td>
<td>Bf</td>
<td></td>
</tr>
<tr>
<td>Factor2</td>
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<td>11.09</td>
<td>12.13</td>
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</tr>
<tr>
<td>Goat Factor1</td>
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<td>109</td>
<td>0.10ac</td>
<td>0.17ab</td>
<td>0.14bc</td>
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<td>Goat Factor2</td>
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<td>0.78ab</td>
<td>0.75bc</td>
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</tr>
<tr>
<td>Goat Factor3</td>
<td>(1.7)</td>
<td>109</td>
<td>0.51ac</td>
<td>0.57ab</td>
<td>0.42bc</td>
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</tr>
<tr>
<td>Goat Factor4</td>
<td>(2.1)</td>
<td>109</td>
<td>0.16ac</td>
<td>0.17ab</td>
<td>0.17bc</td>
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<th>Std. Dev</th>
<th>Std. Error</th>
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<th>Std. Error</th>
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<td>0.03</td>
<td>0.28&lt;sup&gt;bc&lt;/sup&gt;</td>
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<td>.095</td>
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<td>Bf</td>
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<td>0.03</td>
<td>0.26&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.05</td>
<td>0.04</td>
<td>0.28&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.05</td>
<td>&lt;.001**</td>
<td>.006**</td>
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Notes:
- <sup>ac</sup> Means with common superscript are not significantly different at the .0167 level (Bonferroni main effect comparison).
- *Diagnostic question numbers of scenario questions in each factor are presented in parentheses after the factor name.
- **Significant level for the Within Subject tests.

Factor analysis with maximum likelihood and principal components analysis was conducted because Cronbach’s coefficient alpha values in reliability tests were low for each test and each scenario question. Factor analysis showed a certain degree of construct validity that explained whether the diagnostic questions fitted together to constitute a common factor. The general picture was shown from either single diagnostic question factors or multiple diagnostic question factors.

Factor analysis grouped higher-loading factors from each scenario question. Posttest 2 was used as a baseline since students learned more ST when they received posttest 2 compared with the pretest and posttest 1. The overall percentage score from the 6 scenario questions set...
yielded to two factors. Chemical 1, Goat 1, and Swine were loaded on factor 1 while Beef, Goat 2 and chemical 2 were loaded on the factor 2 (Table M.1). The pre-post1-post2 tests on these two factors improved significantly from the Pretest to Posttest 1 and Posttest 2, and from Posttest 1 to Posttest 2. However, the reliability for these two factors was not strong (Cronbach’s coefficient alpha = .3) (Table M.2). In addition, the Pearson correlations between the six scenario questions were very low. Therefore, each scenario question was investigated separately. Goat 1 and goat 2 were grouped into one goat question because the Pearson correlation between Goat 1 and goat 2 in the posttest 2 was .26 and significant at the 0.01 level. Chemical 1 and chemical 2 were grouped into one chemical question although their Pearson correlation was .14 and insignificant. Six scenarios’ questions were then grouped into four main questions (goat, swine, chemical, beef) and loaded with factor analysis.

A number of single-systems-question factors and few multiple-systems-question factors were yielded while some systems questions did not load on any factors. Detailed diagnostic question number and loading for each factor were listed in Table M.3. Goat had 6 factors: The first four factors had single diagnostic questions; factors 5 and 6 had multiple diagnostic questions (Table M.4). Swine had 3 factors and they all had single diagnostic questions (Table M.5). Chemical had 5 factors: factors 2 and 3 had single diagnostic questions; factors 1, 4 and 5 had multiple diagnostic questions (Table M.6). Beef had 5 factors: factors 1, 2, 3 and 5 had single diagnostic questions; factor 4 had multiple diagnostic questions (Table M.7).

To determine whether students’ performance on the higher-loading factors on pre-post1-post2 tests was improved, one-way repeated measures ANOVA was conducted. Overall ANOVA was run 63 times in general linear model for per-post1-post2 tests in design experiment 3. For Bonferroni adjustment, we used Type I Error level .0008 which was Type I Error level .05 divided by 21 factors and by 3 tests that each factor had. There were 6 significant factors (Table M.8). These factors were Goat1 Swine Chemical1 group factor, Goat2 Chemical2 Beef group factor, Swine factor 1 (1.13), Swine factor 2 (1.8), Beef factor 1 (1.7), and Beef factor 4 (1.16+1.17).

Among these 6 factors, the Goat1 Swine Chemical1 group factor was the combination of the Goat1, Swine, and Chemical1 scenario questions; the Goat2 Chemical2 Beef group factor was the combination of the Goat2, Beef, and Chemical2 scenario questions. The Swine factor 1 was the single diagnostic questions 13. The Swine factor2 was the single diagnostic question 8. The Beef factor 1 was the single diagnostic question 7. The beef factor 4 was the combination of diagnostic questions 16 and 17.
APPENDIX N. DESIGN EXPERIMENT 3 RELIABILITY STATISTICS FOR THE SYSTEMS QUESTIONS OF THE SIX SCENARIOS

Table N.1
Reliability Statistics for 35 systems questions of 6 sub-problems

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<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
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<td>.154</td>
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<td>N of systems questions</td>
<td>35</td>
<td>35</td>
<td>35</td>
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a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.2
Cronbach’s coefficient alpha if Systems Questions Deleted from each test

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<th>Posttest2</th>
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<td>-.028</td>
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<td>-.129</td>
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<td>.154</td>
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<td>-.089</td>
<td>.109</td>
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</tr>
<tr>
<td>6Beef1.7sq</td>
<td>-.141</td>
<td>-.137</td>
<td>.142</td>
</tr>
<tr>
<td>6Beef1.8sq</td>
<td>-.216</td>
<td>.031</td>
<td>.198</td>
</tr>
<tr>
<td>6Beef1.12sq</td>
<td>-.128</td>
<td>.020</td>
<td>.192</td>
</tr>
<tr>
<td>6Beef1.15sq</td>
<td>-.156</td>
<td>.022</td>
<td>.143</td>
</tr>
<tr>
<td>6Beef1.16sq</td>
<td>-.144</td>
<td>.013</td>
<td>.159</td>
</tr>
<tr>
<td>6Beef1.17sq</td>
<td>-.118</td>
<td>-.025</td>
<td>.173</td>
</tr>
</tbody>
</table>

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.
Table N.3
**Reliability Statistics for Goat 1 sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s coefficient alpha</td>
<td>-.145</td>
<td>.043</td>
<td>-.055</td>
</tr>
</tbody>
</table>

N of systems questions

The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.4
**Cronbach’s coefficient alpha if Systems Questions Deleted from each test for Goat 1 sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Goat1.2sq</td>
<td>-.251a</td>
<td>-.021a</td>
<td>-.028a</td>
</tr>
<tr>
<td>1Goat1.7sq</td>
<td>-.096a</td>
<td>.135</td>
<td>.082</td>
</tr>
<tr>
<td>1Goat1.13sq</td>
<td>-.127a</td>
<td>-.131a</td>
<td>-.051a</td>
</tr>
<tr>
<td>1Goat1.16sq</td>
<td>-.042a</td>
<td>.252</td>
<td>-.236a</td>
</tr>
<tr>
<td>1Goat1.17sq</td>
<td>-.053a</td>
<td>-.130a</td>
<td>-.022a</td>
</tr>
</tbody>
</table>

The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.5
**Reliability Statistics for Goat 2 sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s coefficient alpha</td>
<td>-2.776E-16</td>
<td>-.112</td>
<td>-.259</td>
</tr>
</tbody>
</table>

N of systems questions

The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.6
**Cronbach’s coefficient alpha if Systems Questions Deleted from each test for Goat 2 sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Goat2.1sq</td>
<td>-.256a</td>
<td>-.117a</td>
<td>-.080a</td>
</tr>
<tr>
<td>2Goat2.2sq</td>
<td>.146</td>
<td>-.169a</td>
<td>-.373a</td>
</tr>
<tr>
<td>2Goat2.5sq</td>
<td>.069</td>
<td>.167</td>
<td>-.041a</td>
</tr>
<tr>
<td>2Goat2.7sq</td>
<td>.099</td>
<td>-.256a</td>
<td>-.363a</td>
</tr>
<tr>
<td>2Goat2.12sq</td>
<td>-.138a</td>
<td>-.148a</td>
<td>-.196a</td>
</tr>
</tbody>
</table>

The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.7
**Reliability Statistics for Swine sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s coefficient alpha</td>
<td>-.476</td>
<td>.286</td>
<td>-.377</td>
</tr>
</tbody>
</table>

N of systems questions

The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.8
**Cronbach’s coefficient alpha if Systems Questions Deleted from each test for Swine sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>3Swine1sq</td>
<td>-.279a</td>
<td>-.171a</td>
<td>-.639a</td>
</tr>
<tr>
<td>3Swine3sq</td>
<td>-.294a</td>
<td>-.178a</td>
<td>-.075a</td>
</tr>
<tr>
<td>3Swine8sq</td>
<td>-.512a</td>
<td>-.254a</td>
<td>-.273a</td>
</tr>
<tr>
<td>3Swine13sq</td>
<td>-.658a</td>
<td>-.248a</td>
<td>-.334a</td>
</tr>
<tr>
<td>3Swine20sq</td>
<td>-.019a</td>
<td>-.221a</td>
<td>-.193a</td>
</tr>
</tbody>
</table>

The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.
Table N.9

**Reliability Statistics for Chemical 1 sub-problems**

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s coefficient alpha</td>
<td>-.467</td>
<td>-.113</td>
<td>-.489</td>
</tr>
<tr>
<td>N of systems questions</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.10

**Cronbach’s coefficient alpha if Systems Questions Deleted from each test for Chemical 1 sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4Chemical1.3sq</td>
<td>.064</td>
<td>-.025</td>
<td>-.408</td>
</tr>
<tr>
<td>4Chemical1.5sq</td>
<td>-.426</td>
<td>.017</td>
<td>.091</td>
</tr>
<tr>
<td>4Chemical1.8sq</td>
<td>-.767</td>
<td>-.197</td>
<td>-.628</td>
</tr>
<tr>
<td>4Chemical1.9sq</td>
<td>-.602</td>
<td>-.165</td>
<td>-.586</td>
</tr>
<tr>
<td>4Chemical1.11sq</td>
<td>-.197</td>
<td>-.082</td>
<td>-.477</td>
</tr>
</tbody>
</table>

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.11

**Reliability Statistics for Chemical 2 sub-problems**

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s coefficient alpha</td>
<td>-1.282</td>
<td>-1.375</td>
<td>-1.051</td>
</tr>
<tr>
<td>N of systems questions</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.12

**Cronbach’s coefficient alpha if Systems Questions Deleted from each test for Chemical 2 sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5Chemical2.1sq</td>
<td>-.689</td>
<td>-.784</td>
<td>-.699</td>
</tr>
<tr>
<td>5Chemical2.3sq</td>
<td>-.742</td>
<td>-.928</td>
<td>-.637</td>
</tr>
<tr>
<td>5Chemical2.4sq</td>
<td>-.402</td>
<td>-.576</td>
<td>-.371</td>
</tr>
<tr>
<td>5Chemical2.6sq</td>
<td>-1.482</td>
<td>-1.335</td>
<td>-1.058</td>
</tr>
<tr>
<td>5Chemical2.9sq</td>
<td>-.999</td>
<td>-.784</td>
<td>-.792</td>
</tr>
</tbody>
</table>

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.13

**Reliability Statistics for Beef sub-problems**

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronbach’s coefficient alpha</td>
<td>-.569</td>
<td>-1.280</td>
<td>-.509</td>
</tr>
<tr>
<td>N of systems questions</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

a. The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Table N.14

**Cronbach’s coefficient alpha if Systems Questions Deleted from each test for Beef sub-problems**

<table>
<thead>
<tr>
<th>Systems questions</th>
<th>Pretest</th>
<th>Posttest1</th>
<th>Posttest2</th>
</tr>
</thead>
<tbody>
<tr>
<td>6Beef1.1sq</td>
<td>-.679</td>
<td>-1.373</td>
<td>-.405</td>
</tr>
<tr>
<td>6Beef1.2sq</td>
<td>-.503</td>
<td>-1.032</td>
<td>-.313</td>
</tr>
<tr>
<td>6Beef1.3sq</td>
<td>-.366</td>
<td>-1.211</td>
<td>-.554</td>
</tr>
<tr>
<td>6Beef1.6sq</td>
<td>-.569</td>
<td>-.964</td>
<td>-.389</td>
</tr>
<tr>
<td>6Beef1.7sq</td>
<td>-.430</td>
<td>-1.425</td>
<td>-.427</td>
</tr>
<tr>
<td>6Beef1.8sq</td>
<td>-.618</td>
<td>-1.049</td>
<td>-.408</td>
</tr>
</tbody>
</table>
To determine which of the 6 scenario questions in each test contributed the most for the significance of the general performance improvement, ANOVA for each scenario question on pre-post1-post2 tests were conducted. There were 6 total scenario questions (Goat1, Goat2, Swine, Chemical1, Chemical2, Beef) in each of the 3 tests. These 3 tests used the same 6 scenario questions. From the ANOVA for each single question, some tests were significant. These 6 scenario questions’ significance contributed to the significance of the previous ANOVA for the 3 total score percentages (pretest, posttest 1, and posttest 2). With Bonferroni Adjustment $p = 0.0167$, the 95% confidence interval for the scenario question Goat 1, the total performance score percentage from the pretest to posttest 2 was increased between 2.36% to 13.42%. However, the improvement of the total score percentage between pretest and posttest 1 was significant at Type I Error level = .05 level but
inconclusive with Bonferroni adjustment. In addition, the improvement of the total score percentage between posttest 1 and posttest 2 was inconclusive. For the scenario question Goat 2, the improvement of all the total score percentage differences for the pretest to posttest 1, pretest to posttest 2, and posttest 1 to posttest 2 were inconclusive. For the scenario question Swine, the two posttest performance scores were better than pretest, and posttest 2 was better than posttest 1. The total score percentage for the pretest to posttest 1 was increased between 91% and 9.36%; the total score percentage for the pretest to posttest 2 was increased between 8.46% and 17.96%; the total score percentage for the posttest 1 to posttest 2 was increased between 3.08% and 13.07%. For the scenario questions in Chemical 1 and Chemical 2, the improvement of the total score percentages between all 3 tests of each question were inconclusive. For the scenario question Beef, the two posttest performance scores were better than the pretest. However, the improvement of the total score percentage between posttest 1 and posttest 2 was significant at Type I Error level = .05 level but inconclusive with Bonferroni adjustment. The total score percentage for the pretest to posttest 1 was increased between 4.84% and 12.04%; the total score percentage for the pretest to posttest 2 was increased between 8.22% and 15.63%. The significant pairs of each question are highlighted in Table N.15.

The systems questions that had a significant level at Type I Error level = .05 in the ANOVA were Goat2.12, Goat1.16, Goat1.17, Swine 8, Swine 13, Swine 20, Chemical2.1, Chemical2.4, Beef1, Beef 2, Beef 6, Beef 7, Beef 8, Beef 16, and Beef 17.

Table N.16

<table>
<thead>
<tr>
<th>Analysis of Variance for Mean Percentage Correct and Standard Deviations on the Pretests and Posttests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest to Posttest 1</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td>Std. Error of M</td>
</tr>
<tr>
<td>95% CI</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Pretest to Posttest 2</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td>Std. Error of M</td>
</tr>
<tr>
<td>95% CI</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Posttest 1 to Posttest 2</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td>Std. Error of M</td>
</tr>
<tr>
<td>95% CI</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Pre to Pst1 to Pst2</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td>Std. Error of M</td>
</tr>
<tr>
<td>95% CI</td>
</tr>
<tr>
<td>N</td>
</tr>
</tbody>
</table>

Note: Repeated measures ANOVA for pre-pst1-pst2 correct percentage w/ Bonferroni adjustment (Bf), p<0.0167.
*p < .0005
APPENDIX O. COMPARISON OF PERFORMANCE ON THE FOUR SWINE DIAGNOSTIC SYSTEMS QUESTIONS FOR STUDENTS IN DESIGN EXPERIMENT 1 AND DESIGN EXPERIMENT 3

Table O.1
**Within-Subjects Factors**

<table>
<thead>
<tr>
<th>Time</th>
<th>Dependent Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PreCrtPct</td>
</tr>
<tr>
<td>2</td>
<td>Post1CrtPct</td>
</tr>
<tr>
<td>3</td>
<td>Post2CrtPct</td>
</tr>
</tbody>
</table>

Table O.2
**Between-Subjects Factors**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>2013</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>109</td>
</tr>
</tbody>
</table>

Table O.3
**Descriptive Statistics**

<table>
<thead>
<tr>
<th>Class</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>PreCrtPct</td>
<td>33.93%</td>
<td>20.095%</td>
<td>112</td>
</tr>
<tr>
<td>2013</td>
<td>34.17%</td>
<td>17.893%</td>
<td>109</td>
</tr>
<tr>
<td>Total</td>
<td>34.05%</td>
<td>18.998%</td>
<td>221</td>
</tr>
<tr>
<td>Post1CrtPct</td>
<td>41.96%</td>
<td>17.506%</td>
<td>112</td>
</tr>
<tr>
<td>2013</td>
<td>41.06%</td>
<td>20.277%</td>
<td>109</td>
</tr>
<tr>
<td>Total</td>
<td>41.52%</td>
<td>18.886%</td>
<td>221</td>
</tr>
<tr>
<td>Post2CrtPct</td>
<td>48.21%</td>
<td>22.187%</td>
<td>112</td>
</tr>
<tr>
<td>2013</td>
<td>47.71%</td>
<td>20.845%</td>
<td>109</td>
</tr>
<tr>
<td>Total</td>
<td>47.96%</td>
<td>21.488%</td>
<td>221</td>
</tr>
</tbody>
</table>

Table O.4
**Multivariate Tests**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Value</th>
<th>Hypothesis</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>.181</td>
<td>24.029a</td>
<td>.181</td>
<td>48.058</td>
<td>1.000</td>
</tr>
<tr>
<td>Wilks’ Lambda</td>
<td>.819</td>
<td>24.029a</td>
<td>.181</td>
<td>48.058</td>
<td>1.000</td>
</tr>
<tr>
<td>Hotelling’s Trace</td>
<td>.221</td>
<td>24.029a</td>
<td>.181</td>
<td>48.058</td>
<td>1.000</td>
</tr>
<tr>
<td>Roy’s Largest Root</td>
<td>.221</td>
<td>24.029a</td>
<td>.181</td>
<td>48.058</td>
<td>1.000</td>
</tr>
<tr>
<td>Time * Gender</td>
<td>.000</td>
<td>.019a</td>
<td>.038</td>
<td>.053</td>
<td></td>
</tr>
<tr>
<td>Wilks’ Lambda</td>
<td>1.000</td>
<td>.019a</td>
<td>.038</td>
<td>.053</td>
<td></td>
</tr>
<tr>
<td>Hotelling’s Trace</td>
<td>.000</td>
<td>.019a</td>
<td>.038</td>
<td>.053</td>
<td></td>
</tr>
<tr>
<td>Roy’s Largest Root</td>
<td>.000</td>
<td>.019a</td>
<td>.038</td>
<td>.053</td>
<td></td>
</tr>
<tr>
<td>Time * Class</td>
<td>.001</td>
<td>.079a</td>
<td>.158</td>
<td>.062</td>
<td></td>
</tr>
<tr>
<td>Wilks’ Lambda</td>
<td>.999</td>
<td>.079a</td>
<td>.158</td>
<td>.062</td>
<td></td>
</tr>
<tr>
<td>Hotelling’s Trace</td>
<td>.001</td>
<td>.079a</td>
<td>.158</td>
<td>.062</td>
<td></td>
</tr>
<tr>
<td>Roy’s Largest Root</td>
<td>.001</td>
<td>.079a</td>
<td>.158</td>
<td>.062</td>
<td></td>
</tr>
</tbody>
</table>

a. Exact statistic
b. Computed using Type I Error level = .05
c. Design: Intercept + Gender + Class; Within Subjects Design: Time
Table O.5

<table>
<thead>
<tr>
<th>Box’s Test of Equality of Covariance Matrices&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box’s M</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>df1</td>
</tr>
<tr>
<td>df2</td>
</tr>
<tr>
<td>Sig.</td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.

<sup>a</sup> Design: Intercept + Gender + Class; Within Subjects Design: Time

Table O.6

<table>
<thead>
<tr>
<th>Mauchly’s Test of Sphericity&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Epsilon&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within Subjects Effect</td>
<td>Approx. W</td>
</tr>
<tr>
<td>Time</td>
<td>.950</td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

<sup>a</sup> May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

<sup>b</sup> Design: Intercept + Gender + Class; Within Subjects Design: Time

Table O.7

<table>
<thead>
<tr>
<th>Tests of Within-Subjects Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
</tr>
<tr>
<td>Time Sphericity Assumed</td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
</tr>
<tr>
<td>Lower-bound</td>
</tr>
<tr>
<td>Time * Gender Sphericity Assumed</td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
</tr>
<tr>
<td>Lower-bound</td>
</tr>
<tr>
<td>Time * Class Sphericity Assumed</td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
</tr>
<tr>
<td>Lower-bound</td>
</tr>
<tr>
<td>Error(Time e) Sphericity Assumed</td>
</tr>
<tr>
<td>Greenhouse-Geisser</td>
</tr>
<tr>
<td>Huynh-Feldt</td>
</tr>
<tr>
<td>Lower-bound</td>
</tr>
</tbody>
</table>

<sup>a</sup> Computed using Type I Error level = .05
Table O.8
Tests of Within-Subjects Contrasts

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Linear</td>
<td>14018.761</td>
<td>1</td>
<td>14018.761</td>
<td>45.180</td>
<td>&lt;.001</td>
<td>.172</td>
<td>45.180</td>
<td>1.000</td>
</tr>
<tr>
<td></td>
<td>Quadratic</td>
<td>27.079</td>
<td>1</td>
<td>27.079</td>
<td>.103</td>
<td>.749</td>
<td>.000</td>
<td>.003</td>
<td>.062</td>
</tr>
<tr>
<td>Time *</td>
<td>Linear</td>
<td>11.631</td>
<td>1</td>
<td>11.631</td>
<td>.037</td>
<td>.847</td>
<td>.000</td>
<td>.037</td>
<td>.054</td>
</tr>
<tr>
<td>Gender</td>
<td>Quadratic</td>
<td>.091</td>
<td>1</td>
<td>.091</td>
<td>.000</td>
<td>.985</td>
<td>.000</td>
<td>.000</td>
<td>.050</td>
</tr>
<tr>
<td>Time * Class</td>
<td>Linear</td>
<td>13.033</td>
<td>1</td>
<td>13.033</td>
<td>.042</td>
<td>.838</td>
<td>.000</td>
<td>.042</td>
<td>.055</td>
</tr>
<tr>
<td></td>
<td>Quadratic</td>
<td>22.366</td>
<td>1</td>
<td>22.366</td>
<td>.085</td>
<td>.771</td>
<td>.000</td>
<td>.085</td>
<td>.060</td>
</tr>
<tr>
<td>Error(Time)</td>
<td>Linear</td>
<td>67642.366</td>
<td>218</td>
<td>310.286</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quadratic</td>
<td>57543.597</td>
<td>218</td>
<td>263.961</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using Type I Error level = .05

Table O.9
Levene’s Test of Equality of Error Variances

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PreCrtPct</td>
<td>2.607</td>
<td>1</td>
<td>219</td>
<td>.108</td>
</tr>
<tr>
<td>Post1CrtPct</td>
<td>3.813</td>
<td>1</td>
<td>219</td>
<td>.052</td>
</tr>
<tr>
<td>Post2CrtPct</td>
<td>.424</td>
<td>1</td>
<td>219</td>
<td>.516</td>
</tr>
</tbody>
</table>

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a. Design: Intercept + Gender + Class; Within Subjects Design: Time

Table O.10
Tests of Between-Subjects Effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td></td>
<td>730774.013</td>
<td>1</td>
<td>730774.013</td>
<td>1195.867</td>
<td>&lt;.001</td>
<td>.846</td>
<td>1195.867</td>
<td>1.000</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td>974.336</td>
<td>1</td>
<td>974.336</td>
<td>1.594</td>
<td>.208</td>
<td>.007</td>
<td>1.594</td>
<td>.242</td>
</tr>
<tr>
<td>Class</td>
<td></td>
<td>3.868</td>
<td>1</td>
<td>3.868</td>
<td>.006</td>
<td>.937</td>
<td>.000</td>
<td>.006</td>
<td>.051</td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td>133216.085</td>
<td>218</td>
<td>611.083</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using Type I Error level = .05

Table O.11
Parameter Estimates

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Parameter</th>
<th>B</th>
<th>Std. Error</th>
<th>t</th>
<th>Sig.</th>
<th>95% Confidence Interval</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PreCrtPct</td>
<td>Intercept</td>
<td>33.548</td>
<td>1.977</td>
<td>16.972</td>
<td>&lt;.001</td>
<td>29.652</td>
<td>37.443</td>
<td>.569</td>
<td>16.972</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>2.277</td>
<td>2.758</td>
<td>.826</td>
<td>.410</td>
<td>-3.158</td>
<td>7.713</td>
<td>.003</td>
<td>.826</td>
</tr>
<tr>
<td></td>
<td>[Class=2013]</td>
<td>-.453</td>
<td>2.576</td>
<td>-.176</td>
<td>.861</td>
<td>-5.530</td>
<td>4.624</td>
<td>.000</td>
<td>.176</td>
</tr>
<tr>
<td></td>
<td>[Class=2014]</td>
<td>0b</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post1CrtPct</td>
<td>Intercept</td>
<td>40.347</td>
<td>1.964</td>
<td>20.548</td>
<td>&lt;.001</td>
<td>36.477</td>
<td>44.217</td>
<td>.659</td>
<td>20.548</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>2.573</td>
<td>2.740</td>
<td>.939</td>
<td>.349</td>
<td>-2.827</td>
<td>7.972</td>
<td>.004</td>
<td>.939</td>
</tr>
<tr>
<td></td>
<td>[Class=2013]</td>
<td>.676</td>
<td>2.559</td>
<td>.264</td>
<td>.792</td>
<td>-4.368</td>
<td>5.719</td>
<td>.000</td>
<td>.264</td>
</tr>
<tr>
<td></td>
<td>[Class=2014]</td>
<td>0b</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post2CrtPct</td>
<td>Intercept</td>
<td>46.888</td>
<td>2.234</td>
<td>20.984</td>
<td>&lt;.001</td>
<td>42.484</td>
<td>51.292</td>
<td>.669</td>
<td>20.984</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
<td>2.975</td>
<td>3.118</td>
<td>.954</td>
<td>.341</td>
<td>-3.169</td>
<td>9.120</td>
<td>.004</td>
<td>.954</td>
</tr>
<tr>
<td></td>
<td>[Class=2013]</td>
<td>.238</td>
<td>2.912</td>
<td>.082</td>
<td>.935</td>
<td>-5.502</td>
<td>5.977</td>
<td>.000</td>
<td>.082</td>
</tr>
<tr>
<td></td>
<td>[Class=2014]</td>
<td>0b</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using Type I Error level = .05
b. This parameter is set to zero because it is redundant.
Table O.12

**Grand Mean**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Std. Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.175&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.960</td>
<td>39.283</td>
<td>43.068</td>
</tr>
</tbody>
</table>

* Covariates appearing in the model are evaluated at the following values: Gender = .32.

Table O.13

**Class Estimates**

<table>
<thead>
<tr>
<th>Class</th>
<th>Mean</th>
<th>Std. Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>41.252&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.352</td>
<td>38.588</td>
<td>43.916</td>
</tr>
<tr>
<td>2014</td>
<td>41.099&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.370</td>
<td>38.398</td>
<td>43.799</td>
</tr>
</tbody>
</table>

* Covariates appearing in the model are evaluated at the following values: Gender = .32.

Table O.14

**Pairwise Comparisons**

<table>
<thead>
<tr>
<th>(I) Class</th>
<th>(J) Class</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
</table>

Based on estimated marginal means

* Adjustment for multiple comparisons: Bonferroni.

Table O.15

**Univariate Tests**

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Mean Square</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error</td>
<td>44405.362</td>
<td>218</td>
<td>203.694</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The F tests the effect of Class. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

* Computed using Type I Error level = .05

Table O.16

**Time Estimates**

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>Std. Error</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>34.053&lt;sup&gt;y&lt;/sup&gt;</td>
<td>1.282</td>
<td>31.526</td>
<td>36.579</td>
</tr>
<tr>
<td>Posttest1</td>
<td>41.511&lt;sup&gt;y&lt;/sup&gt;</td>
<td>1.273</td>
<td>39.002</td>
<td>44.021</td>
</tr>
<tr>
<td>Posttest2</td>
<td>47.962&lt;sup&gt;y&lt;/sup&gt;</td>
<td>1.449</td>
<td>45.106</td>
<td>50.818</td>
</tr>
</tbody>
</table>

* Covariates appearing in the model are evaluated at the following values: Gender = .32.

Table O.17

**Pairwise Comparisons**

<table>
<thead>
<tr>
<th>(I) Time</th>
<th>(J) Time</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>Posttest1</td>
<td>-7.458&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.423</td>
<td>&lt;.001</td>
<td>-10.893</td>
<td>-4.024</td>
</tr>
<tr>
<td></td>
<td>Posttest2</td>
<td>-13.909&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.676</td>
<td>&lt;.001</td>
<td>-17.953</td>
<td>-9.866</td>
</tr>
<tr>
<td>Posttest1</td>
<td>Pretest</td>
<td>7.458&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.423</td>
<td>&lt;.001</td>
<td>4.024</td>
<td>10.893</td>
</tr>
<tr>
<td></td>
<td>Posttest2</td>
<td>-6.451&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.721</td>
<td>.001</td>
<td>-10.603</td>
<td>-2.299</td>
</tr>
<tr>
<td>Posttest2</td>
<td>Pretest</td>
<td>13.909&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.676</td>
<td>&lt;.001</td>
<td>9.866</td>
<td>17.953</td>
</tr>
<tr>
<td></td>
<td>Posttest1</td>
<td>6.451&lt;sup&gt;*&lt;/sup&gt;</td>
<td>1.721</td>
<td>.001</td>
<td>2.299</td>
<td>10.603</td>
</tr>
</tbody>
</table>

Based on estimated marginal means

* The mean difference is significant at the .05 level.

* Adjustment for multiple comparisons: Bonferroni.
Table O.18  
*Multivariate Tests*

<table>
<thead>
<tr>
<th>Test</th>
<th>Value</th>
<th>F</th>
<th>df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Noncent. Parameter</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pillai’s trace</td>
<td>.252</td>
<td>36.595^a</td>
<td>2.00</td>
<td>217.000</td>
<td>&lt;.001</td>
<td>.252</td>
<td>73.190</td>
<td>1.00</td>
</tr>
<tr>
<td>Wilks’ lambda</td>
<td>.748</td>
<td>36.595^a</td>
<td>2.00</td>
<td>217.000</td>
<td>&lt;.001</td>
<td>.252</td>
<td>73.190</td>
<td>1.00</td>
</tr>
<tr>
<td>Hotelling’s trace</td>
<td>.337</td>
<td>36.595^a</td>
<td>2.00</td>
<td>217.000</td>
<td>&lt;.001</td>
<td>.252</td>
<td>73.190</td>
<td>1.00</td>
</tr>
<tr>
<td>Roy’s largest root</td>
<td>.337</td>
<td>36.595^a</td>
<td>2.00</td>
<td>217.000</td>
<td>&lt;.001</td>
<td>.252</td>
<td>73.190</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Each F tests the multivariate effect of Time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic  
b. Computed using Type I Error level = .05

Table O.19  
*Class * Time*

<table>
<thead>
<tr>
<th>Class</th>
<th>Time</th>
<th>Mean</th>
<th>Std. Error</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower Bound</td>
</tr>
<tr>
<td>2013</td>
<td>Pretest</td>
<td>33.827^a</td>
<td>1.805</td>
<td>30.270</td>
</tr>
<tr>
<td></td>
<td>Posttest1</td>
<td>41.849^a</td>
<td>1.793</td>
<td>38.316</td>
</tr>
<tr>
<td></td>
<td>Posttest2</td>
<td>48.081^a</td>
<td>2.040</td>
<td>44.060</td>
</tr>
<tr>
<td>2014</td>
<td>Pretest</td>
<td>34.279^a</td>
<td>1.829</td>
<td>30.673</td>
</tr>
<tr>
<td></td>
<td>Posttest1</td>
<td>41.173^a</td>
<td>1.817</td>
<td>37.592</td>
</tr>
<tr>
<td></td>
<td>Posttest2</td>
<td>47.843^a</td>
<td>2.068</td>
<td>43.767</td>
</tr>
</tbody>
</table>

a. Covariates appearing in the model are evaluated at the following values: Gender = .32.
APPENDIX P. INFORMED CONSENT DOCUMENT

Title of Study:  Food Systems Veterinary Medicine for the 21st Century

Investigators:  Scott Hurd, DVM, PhD; Co-PI: Tao, Li-Shan, MBA; Jared Danielson, PhD

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION
The purpose of this study is to evaluate the effects of using systems thinking skills on solving multi-disciplinary veterinary problems. You are being invited to participate in this study because you are a student in a program that is using or planning to use the systems thinking skills.

DESCRIPTION OF PROCEDURES
If you agree to participate in this study, your participation will occur up to several times during the year, and might involve one or more of the following: 1) completing questionnaires about your experience with systems thinking, and/or 2) participating in an individual interview in which you will discuss your experience on using systems thinking skills while a researcher records your interactions with the interviewer and asks you questions. Your responses to survey and interview questions are voluntary and will remain confidential. While responding the questionnaire, you may skip any question that you do not wish to answer or that makes you feel uncomfortable. The interviews may be recorded, and the audio recordings will be deleted within two years of the completion of the study.

RISKS
There are no foreseeable risks at this time from participating in this study.

BENEFITS
If you decide to participate in this study there may be no direct benefit to you. It is hoped that the information gained in this study will benefit society by helping educators know how to best utilize and improve systems thinking techniques to promote veterinary students learning.

COSTS AND COMPENSATION
You will not have any costs or compensation from participating in this study.

PARTICIPANT RIGHTS
Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide not to participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled.

CONFIDENTIALITY
Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal
government regulatory agencies, auditing departments of Iowa State University, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, any notes, audio recordings, or survey responses will be kept locked (if paper) or password protected (if electronic), and will be deleted within two years of the completion of the study. If the results are published, your identity will remain confidential.

QUESTION OR PROBLEMS
You are encouraged to ask questions at any time during this study.

- For further information about the study contact Scott Hurd, 1710 Vet Med, Iowa State University, Ames, IA 50011 (515-294-7905) shurd@iastate.edu

- If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

***************************************************************************

PARTICIPANT SIGNATURE
Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the written informed consent prior to your participation in the study.

Participant’s Name (printed) ____________________________________________

_________________________________________ (Participant’s Signature) (Date)

INVESTIGATOR STATEMENT
I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.

_________________________________________ (Signature of Person Obtaining Informed Consent) (Date)