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Misunderstandings of atmospheric carbon budgets: Advances toward remediation of a common student misconception

Collin Peter Reichert

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Misunderstandings of atmospheric carbon budgets: Advances toward remediation of a common student misconception

by

Collin Peter Reichert

A thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Geology

Program of Study Committee:
Cinzia Cervato, Major Professor
William A. Gallus Jr.
Dale Niederhauser

Iowa State University
Ames, Iowa
2011

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CHAPTER 1: General Background

Background

Students enrolled in introductory geoscience classes come with a plethora of ideas regarding the scientific concepts they will encounter in that course. It is of utmost importance for an instructor to know what students’ prior knowledge is in order to make appropriate pedagogical decisions about what content, materials, or instructional strategies to employ. As many instructors soon discover, many students’ ideas of scientific topics do not match the scientifically accepted understanding of that concept. Thus, for learning to occur, instructors must often go about the arduous task of, first, convincing students that their ideas are not accurate, second, introducing students to the scientific understanding of the concept in question, and finally convincing students the scientific idea is superior to the students’ naïve understanding. An instructor can only be successful in the above if they possess a deep and robust understanding of how people learn.

Multiple, non-exclusive theories of learning exist and this chapter will examine four of them: Behavioral Learning Theory (BLT), Developmental Learning Theory (DLT), Social Learning Theory (SLT) and Constructivist Learning Theory (CLT). These theories will be discussed individually but important to note is that considerable overlap exists between them. All of the theories should aid a teacher in making decisions regarding instruction and sometimes one theory may be more applicable than another.
American educational systems still struggle to effectively integrate all four learning theories into practice (Champagne & Hornig, 1987).

Behavioral psychologists are primarily concerned with what they consider “observable” behavior, insisting it is impossible to fully access and assess a person’s thinking. Behavioral psychologists have come to define learning as an enduring change in behavior over a period of time which is not a result of developmental processes such as physiological maturation (Eggen & Kauchack, 1992; Gage & Berliner, 1988). Thus, behaviorists conceptualize learning as connections between stimuli and responses, i.e. if, over time, change occurs in an individual’s response to the same stimuli with the same or similar conditions, then learning has occurred (Bransford, Brown & Cocking, 2000). Teaching influenced by BLT therefore tends to focus on encouraging desired student behavior or changing undesired student behavior, whatever that may be, to desired student behavior. Such tasks would likely be accomplished, in behaviorist tradition, through the use of use of contiguity (Eggen & Kauchack, 1992; Woolfolk, 2007) by administering reinforcement and/or punishments (Woolfolk, 2007).

The principle of contiguity refers to the association of behaviors with sensations that students may develop when a behavior and a sensation occur together repeatedly. The use of reinforcement serves to increase the duration or frequency of a behavior determined to be desirable (Woolfolk, 2007). A teacher can use both positive reinforcement (adding stimuli following certain behaviors, such as praising a student after
contributing to a class discussion\(^1\) or negative reinforcement (removing stimuli following a certain behaviors, such as not assigning homework after students spend the entire class period on task) to increase a desired behavior. The use of punishment serves to decrease the duration or frequency of a behavior determined to be undesirable, such as adding extra work or eliminating certain privileges for students who are disruptive in class. Reinforcement and punishment refer to different processes, i.e. the increase or decrease in a certain behavior, respectively, and should not be confused.

Jean Piaget held that learners proceed through various stages of cognitive development through physiological maturation (Inhelder & Piaget, 1958; Karplus, 1977) and these stages form the basic tenets of DLT. Piaget’s developmental stages are, in ontogenetic order: a. the sensorimotor stage, in which learners begin to use memory, thought, imitation etc. \textit{(approximately} from ages 0-2); b. the pre-operational stage, in which learners develop language, symbolism, and logical thinking \textit{(approximately} from ages 2-7); c. the concrete operational stage, in which students apply logical reasoning to concrete (physical) problems, and understand conservation and reversibility \textit{(approximately} from ages 7-11); and d. the formal operational stage, in which students are capable of abstract thought and can apply it to abstract problems, and develop societal concerns as well as identity \textit{(approximately} from age 11 into adulthood) (Inhelder & Piaget, 1958; Karplus, 1977; Woolfolk, 2007). The ages associated with reaching these cognitive development stages are highly variable from person to person dependent on a

\(^1\) This is just an example of what someone might perceive as positive feedback to encourage and increase student response. In reality, praise during class time has been found to diminish student creativity and therefore discourage thinking and unconventional responses from students (Penick, 1995).
multitude of factors, which is why the ages assigned to each stage above are only approximations. In addition, inconsistencies in students thinking are often observed and students often do not fit into a particular stage completely, as originally defined by Piaget, who later abandoned age classifications on these stages (Woolfolk, 2007).

Piaget (1973) held that education was crucial to human development: “Thus education is...a necessary formative condition toward natural development itself.” Learners proceed through the stages outlined above based not only on physical maturation but experience with the physical environment, social transmission and what Piaget termed “equilibration” (Karplus, 1977). Thus, DLT here begins to have considerable overlap with SLT (social transmission), and CLT (experiences and equilibration). The environment provided in formal or informal educational settings, such as social interaction and experiences with concrete and/or abstract problems, are therefore absolutely crucial to human development, as Piaget (1973) indicated.

All students can benefit from the use of concrete representations to help make sense of abstract ideas. (Some refer to concrete activities as “hands-on” activities). It is important to note that simply providing students with concrete representations is hardly ever sufficient for developing science ideas, which also require significant cognitive effort and social interaction to fully understand (Driver, Asoko, Leach, Mortimer & Scott, 1994).

SLT has been heavily influenced by the work of the early 20th century psychologist Lev Vygotsky (1978). Vygotsky saw learning as taking place in the presence of others (Dixon-Krauss, 1996) and higher-order mental processes (reasoning,
problem solving, etc.) developing with the aid of language, signs and symbols (Woolfolk, 2007). In contrast to Piaget, who thought learners proceeded from internal formulation of meaning to a social expression of that meaning later, Vygotsky held that learners first “co-construct” knowledge socially before they are able to internalize that knowledge and use it on their own. There is similarity in Piaget’s ideas of cognitive development and those of Vygotsky. Both indicate that cognitive development proceeded from the concrete to the abstract. What is different between their ideas is the mechanism by which cognitive development occurs. Piaget thought that individual mental processes and individuals making sense of their experiences led to cognitive development, with less emphasis placed on social inputs. Vygotsky, on the other hand, thought that human activities cannot be understood outside of cultural settings (Woolfolk, 2007). Thus, SLT says students must first carry out mental activities in a social context, with the aid of cultural or psychological tools, before they can do it individually, especially when it is a higher-order mental process.

According to social psychologists, a gap exists between what a person can cognitively achieve individually and what they could achieve with the assistance of an advanced peer or adult; this gap is referred to as the “zone of proximal development” (Vygotsky, 1978; Dixon-Krauss, 1996; Woolfolk, 2007). The implication for teaching is that instruction should target the zone of proximal development and avoid instruction which targets what students already know, or what is yet too difficult for them to tackle. A teacher must therefore be well informed on what their students know if they are to teach to the zone of proximal development.
CLT has also gone by the name of Cognitive Learning Theory and, like DLT and SLT, has investigated the process of thinking, whereas behaviorism was concerned with directly observable behavior. CLT is also largely influenced by the work of Jean Piaget (1963). Piaget described knowledge as generated by the creation of mental representations of the world, or schemas, that change through time based on an individual’s experiences (Piaget, 1963; Driver et. al. 1994a; Woolfolk, 2007). According to Piaget, individuals undergo a continuous attempt at equilibration, or testing schemas’ adequacy in explaining what a person experiences. Experiences can either be explained by an existing schema in which students assimilate the new experience, or, if an experience cannot be adequately explained by an existing schema (and the experience is not simply dismissed by the person as invalid), the person goes through the process of adaptation, in which the schema is changed or replaced to fit the new information (Piaget, 1963; Saunders, 1992; Woolfolk, 2007).

Vygotsky is also considered a constructivist as he viewed cognitive development as a mental construction, i.e. students make sense of new information by fitting it in with what they already know. Hence, a learner’s prior knowledge is of vital importance to CLT. Science students will come to the classroom with pre-existing ideas to explain natural phenomena that they have constructed from prior experiences in primary and secondary classes or in informal settings (Appleton, 1993; Driver et. al. 1994a; Driver, Squires, Rushworth & Wood-Robinson, 1994; Bransford, Brown & Cocking, 2000; Pratt, 2002; Woolfolk, 2007). Ideas students have about nature often do not match scientific understanding (Smith, 1990) and present a significant challenge to educators because
learners will often not give up their ideas easily, even in the face of contrary evidence (Stepans, Beiswenger & Dyche, 1986; Watson & Konicek, 1990).

Research shows that informal knowledge (learners’ ideas about the world that are inconsistent with the scientific understanding of the world) often share common themes even in people of different countries, languages or educational systems (Driver et. al., 1994a and b). This could be because different ways humans can understand natural phenomena are limited by the way the world works. For example, two persons’ experiences with falling objects will be similar regardless of social context and thus people from opposite sides of the globe may construct the same informal knowledge regarding the motion of falling bodies. Social influences often reinforce informal ideas because other individuals in a given culture have had similar experiences with the natural world. Thus, informal, “commonsense” ideas are often socialized and become a part of not only an individual’s personal interpretation of the world but are tied to their social identity as well. Students are not likely to discover scientific knowledge on their own by simply investigating phenomena because scientific knowledge is often not intuitive (Budd Rowe and Holland, 1990). Scientific knowledge is validated, communicated and constructed socially, and the challenge educators face is developing a “critical perspective on scientific culture among students” (Driver et. al. 1994a: p. 11).
Thesis Organization

The work presented in this thesis exhibits a focus on constructivist learning theory principles; though, as indicated earlier, one learning theory is not completely independent of another. As Piaget indicated, cognitive development (knowledge construction) is coupled with physiological development and in that respect developmental learning theory is inextricable from constructivist learning theory. And, as indicated by Vygotsky and later reinforced by constructivists such as Driver et. al. (1994a) knowledge construction of scientific ideas demands a social environment, and thus social learning theory is equally inextricable from the constructivist. Similarly, the cognitive engagement required for knowledge construction to occur often necessitates the provision of stimuli to students who so frequently suffer from limited self-efficacy, thus entangling behavioral learning theory with the constructivist as well. The choice to focus on constructivist learning principles was made because the work described in this thesis concerns the identification and evaluation of prior knowledge held by students in introductory geoscience classes and, moreover, pedagogical decisions made to create cognitive dissonance (disequilibrium) among the majority students in the study who held incorrect ideas about a scientific concept.

This thesis is organized as follows: Chapter 2 describes a survey completed by students enrolled in an introductory physical geology class during two consecutive years. The survey’s purpose was to quantify and investigate a common misconception held by students with regard to budgets, specifically atmospheric carbon budgets. Chapter 2 is in the form of a paper in preparation to be submitted to the International Journal of
Environmental and Science Education (IJESE). Chapter 3 is another paper in preparation to be jointly submitted to the IJESE; it describes a remediation assignment constructed to directly challenge specific characteristics of the misconceptions identified and studied in Chapter 2, particularly the association of inflow rates with overall reservoir levels.

Chapter 4 describes the general conclusions to this thesis. An appendix provides a copy of the survey instrument described in Chapter 2.
References


CHAPTER 2: Students’ misconceptions of atmospheric carbon budgets: Undergraduate students’ perceptions of mass balance

A paper in preparation for submission to the International Journal of Environmental and Science Education.

Collin Reichert,2 Cinzia Cervato,2 Michael Larsen,3 and Dale Niederhauser4

Abstract

With recent U.S. government efforts to develop policy procedures for addressing climate change, it is imperative that the public understand basic aspects of climate change in order for them to understand such policy. However, widespread misconceptions of basic atmospheric principles exist. In this study we document levels of misunderstanding that U.S. undergraduate students have with respect to atmospheric carbon budgets and factors that may account for variability in their understanding. Students enrolled in an introductory geology course (n = 947) completed a survey on atmospheric carbon budgets in two sequential semesters. Results indicated that most students did not have a basic understanding of mass-balance problems, and that their misunderstanding varied according to gender and their interest in science. Further, students tended to exhibit very poor graphical interpretation skills when examining mass-balance graphs.

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Introduction

The rationale for this study developed out of one of the co-author’s consistent observations of introductory meteorology students’ poor performance on an assignment investigating the relationship between atmospheric radiation balance and temperature. Stock-flow (or budget) systems, in which the level of a stock is controlled by the balance of the inflow and outflow rates of that system, are a source of confusion and misunderstanding for many U.S. college students, even for graduate students at prestigious universities (Sterman & Booth Sweeney, 2007). If these misunderstandings persist among highly educated adults one can assume the general public also misunderstands these budget concepts.

Understanding budget systems requires an understanding of conservation of mass, which, in addition to being a fundamental physical principle, has many practical applications in day-to-day life. These misunderstandings of budget concepts offers a possible explanation for some pressing problems in the US including: Mismanagement of the federal budget—a balance of tax revenue and expenditures; the apparent inability of some citizens to balance their personal financial budgets—a balance of their personal income and spending; and perhaps the widespread difficulty in managing a healthy body weight—a balance of caloric intake and usage. Budget misunderstandings could also help explain some of the lack of public support for climate change policy, the urgency of which requires citizens and policy makers to understand that atmospheric carbon dioxide (CO₂) levels can only decrease when emission levels fall below removal rates of CO₂ from the atmosphere (Sterman & Booth Sweeney, 2007).
Research has shown that although the majority of the U.S. public views the seriousness of climate change as real, this number is declining (Gallup, 2010a, 2010b), and climate change misconceptions are common in the U.S. and other countries. For example, researchers have demonstrated that many people confuse ozone layer depletion with global warming or assume a cause and effect relationship between these two separate environmental problems (Anderson & Wallin, 2000; Boyes & Stanisstreet, 1992, 1993, 1994, 1997, 2001; Daniel, Stanisstreet & Boyes, 2004). More relevant to this study are the well documented misunderstandings held by students and the public regarding atmospheric CO\textsubscript{2} and other budgets (Booth Sweeney & Sterman, 2007; Cronin & Gonzales, 2007; Cronin, Gonzales & Sterman, 2009; Sterman, 2008; Moxnes & Saysel, 2009; Sterman & Booth Sweeney, 2007).

Researchers have examined whether different presentations of budget information, such as through non-graphical representations (Cronin et al., 2009) or using seemingly more familiar budget scenarios such as a bank account (Cronin & Gonzales, 2007) had an effect on highly educated graduate (Cronin et al., 2009) and undergraduate students (Cronin & Gonzales, 2007) understanding of budgets. These studies showed that the use of graphs improves student interpretation of budget data (as opposed to data presented in a table or text) while there was no significant difference when more familiar models like bank accounts were used.

Further, Cronin et al. (2009) presented graduate students from MIT with bar graphs rather than the (time-series) line graphs more commonly used by scientists, and “simpler” line graphs with fewer data points. Results showed that these different
graphical representations of data had no significant effect when student were tested on the material. Cronin et al. (2009) also tested the effect of having students “primed” about the concepts that they would need to apply to solve a task, i.e., students reviewed relevant concepts prior to performing the task. Some improvements were observed but the majority of students failed to interpret even the priming activity correctly. Of the MIT graduate students who answered incorrectly, 70% simply matched patterns of CO$_2$ inflow with overall atmospheric CO$_2$ levels, violating the law of conservation of mass. In the present research, we examined student understanding of stock-flow relationships using data from a large and diverse group of undergraduate students, and hypothesize about the relationships among student characteristics and their misunderstandings of stock-flow systems.

In this study we focus specifically on students’ misunderstanding of budgets related to understanding atmospheric carbon levels, which is an important topic for geoscience majors, but also a topic that is critical for the general public to understand. The purpose of the research is to document misconceptions of atmospheric carbon budgets among undergraduate students so that we can begin to systematically address these misconceptions through coursework and experiential activities.
**Method**

During two consecutive fall semesters, students enrolled in an introductory geology course (n=947) completed an online survey (see appendix) which was used to collect demographic information, opinions about global climate change and their views regarding the scientific consensus on global climate change, and atmospheric carbon budget knowledge during the first two weeks of class. Demographic information was collected to describe the sample and to use in tests for examining relationships among these characteristics and budget knowledge. Survey items addressed the following demographic information: gender, age, college in which they are majoring, year in school, mother’s and father’s level of education, interest in science, and concern for the environment.

Students also answered eight questions to determine their level of action for environmental protection or conservation: Whether students recycled, reduced consumption, conserved water, decreased energy use by decreasing fossil fuel transportation use, decreased domestic energy use, discussed environmental issues with others, learned about environmental issues, or used renewable energy sources. Students chose one of three options to describe whether they engaged in the environmental actions: “usually,” “sometimes” or “never,” and answered “yes” or “no” to usage of renewable energy sources items. Students were coded as having low environmental action levels if they engaged, at least sometimes, in 0 to 2 actions; as having medium environmental action levels if they engaged in 3 or 4 actions, and high environmental action if they engaged in 5 or more actions. The survey was validated for content
accuracy by geologists and for comprehension and design validity by statistical survey experts. The general demographic makeup of the participants in this study is presented in Table 2.1 and Table 2.2.

To determine students’ opinions about global climate change and their views regarding the scientific consensus on global climate change, a series of statements were presented and students selected the statement that most closely matched their views.

Survey questions testing budget knowledge were based on recently observed carbon emission and removal rates, and as projected rates for the remainder of the 21st century in a hypothetical scenario (Fig. 2.1). Based on the atmospheric carbon budget scenario in Figure 2.1a, students chose an emission projection that they thought would lead to decreasing atmospheric carbon levels (Q1). After examining the hypothetical scenario in Figure 2.1b, students answered questions on what year atmospheric carbon levels would begin decreasing (Q2), in what years atmospheric carbon would be stable (Q3) and in what year maximum carbon levels would be reached (Q4). In addition to textual descriptions, students examined a graph depicting hypothetical carbon emissions and removal over the course of 75 years (Fig. 2.2). From the graph, students indicated at what point maximum (Q5) and minimum (Q6) levels of atmospheric carbon concentrations would occur.
Table 2.1: Demographic makeup of study participants (n=947).

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Categories</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Female</td>
<td>49.84</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>50.16</td>
</tr>
<tr>
<td>Age</td>
<td>15-18</td>
<td>26.24</td>
</tr>
<tr>
<td></td>
<td>19-21</td>
<td>60.85</td>
</tr>
<tr>
<td></td>
<td>22-24</td>
<td>9.95</td>
</tr>
<tr>
<td></td>
<td>25-27</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td>28-30</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>over 40</td>
<td>0.53</td>
</tr>
<tr>
<td>Year</td>
<td>Fresh.</td>
<td>30.79</td>
</tr>
<tr>
<td></td>
<td>Soph.</td>
<td>35.03</td>
</tr>
<tr>
<td></td>
<td>Junior</td>
<td>20.38</td>
</tr>
<tr>
<td></td>
<td>Senior</td>
<td>13.80</td>
</tr>
<tr>
<td>College</td>
<td>Liberal Arts and Sciences</td>
<td>44.30</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>20.13</td>
</tr>
<tr>
<td></td>
<td>Human Sciences</td>
<td>14.38</td>
</tr>
<tr>
<td></td>
<td>Agriculture and Life Sciences</td>
<td>11.71</td>
</tr>
<tr>
<td></td>
<td>Design</td>
<td>6.92</td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td>2.24</td>
</tr>
<tr>
<td></td>
<td>Veterinary</td>
<td>0.32</td>
</tr>
<tr>
<td>Mother's Education</td>
<td>Did not graduate high school</td>
<td>2.22</td>
</tr>
<tr>
<td></td>
<td>High school</td>
<td>19.32</td>
</tr>
<tr>
<td></td>
<td>Some college</td>
<td>17.00</td>
</tr>
<tr>
<td></td>
<td>Two-year degree program</td>
<td>17.00</td>
</tr>
<tr>
<td></td>
<td>Bachelor's degree</td>
<td>32.63</td>
</tr>
<tr>
<td></td>
<td>Degree beyond Bachelor's</td>
<td>11.83</td>
</tr>
<tr>
<td>Father's Education</td>
<td>Did not graduate high school</td>
<td>2.43</td>
</tr>
<tr>
<td></td>
<td>High school</td>
<td>24.63</td>
</tr>
<tr>
<td></td>
<td>Some college</td>
<td>12.37</td>
</tr>
<tr>
<td></td>
<td>Two-year degree program</td>
<td>11.95</td>
</tr>
<tr>
<td></td>
<td>Bachelor's degree</td>
<td>31.71</td>
</tr>
<tr>
<td></td>
<td>Degree beyond Bachelor's</td>
<td>16.91</td>
</tr>
<tr>
<td>Concern for Environment</td>
<td>Very concerned</td>
<td>25.03</td>
</tr>
<tr>
<td></td>
<td>Somewhat concerned</td>
<td>52.90</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>15.95</td>
</tr>
<tr>
<td></td>
<td>Not very concerned</td>
<td>5.38</td>
</tr>
<tr>
<td></td>
<td>Not concerned</td>
<td>0.74</td>
</tr>
</tbody>
</table>
Table 2.2: Percentage of students reporting participation in environmental actions.

<table>
<thead>
<tr>
<th>Environmental Action</th>
<th>% Usually</th>
<th>% Sometimes</th>
<th>% Never</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycle</td>
<td>50.79</td>
<td>46.67</td>
<td>2.54</td>
</tr>
<tr>
<td>Reduce consumption</td>
<td>15.84</td>
<td>46.46</td>
<td>37.70</td>
</tr>
<tr>
<td>Reduce water use</td>
<td>56.07</td>
<td>39.28</td>
<td>4.65</td>
</tr>
<tr>
<td>Reduce energy use</td>
<td>66.95</td>
<td>29.36</td>
<td>3.69</td>
</tr>
<tr>
<td>Reduce domestic energy use</td>
<td>39.28</td>
<td>51.95</td>
<td>8.77</td>
</tr>
<tr>
<td>Talk about environmental issues</td>
<td>12.35</td>
<td>51.95</td>
<td>35.70</td>
</tr>
<tr>
<td>Learn about environmental issues</td>
<td>21.01</td>
<td>68.43</td>
<td>10.56</td>
</tr>
<tr>
<td>Use renewable energy</td>
<td>7.18</td>
<td>92.82</td>
<td></td>
</tr>
</tbody>
</table>

The survey was administered to undergraduates enrolled in an introductory physical geology class at a large Midwestern university using the WebCT/Blackboard online class management system. Survey completion was required and students received a fixed amount of credit, but students were made aware that accuracy of answers would not count toward their grade since the content had not yet been presented in the course.

a) Currently, the amount of carbon that human activity inputs into the atmosphere is around 8 billion tons per year. The amount of carbon that is removed from the atmosphere by oceans, trees, and other factors is about 50% of that or 4 billion tons per year. The carbon input into the atmosphere by human activity has been increasing and is predicted to continue increasing.

b) If we steadily decreased our carbon input to the atmosphere starting in the year 2025, reached the removal rate (i.e. the amount of carbon removed from the atmosphere by the Earth) by the year 2075, kept emissions constant until 2099 and then dropped below the removal rate in 2100, in what year...

Figure 2.1: Atmospheric carbon scenarios presented to students on the survey. Four of the survey budget questions were based on these scenarios.
Figure 2.2: Graph presented to students on survey; students interpreted maximum and minimum atmospheric carbon levels from the graph.
Results

Initial analysis examined whether data collected during the two sampling periods (consecutive years) could be collapsed into a single sample. Results revealed significant differences between the two groups on science interest and opinion of the seriousness of climate change using Bonferroni correction for twenty-two independent comparisons. In light of these findings we kept the two groups separate for science interest and opinion of the seriousness of climate change, and collapsed data for the remaining factors into a single group for analysis.

While an in-depth explanation of what accounts for these differences is beyond the scope of this paper, we speculate that widespread media coverage of local and regional flooding that occurred only months before the first year survey administration may have played into the first year group having more serious perspectives on climate change. Similar relationships among media coverage and public perception of global warming have been demonstrated in other studies (e.g. Yuki & Midori, 2009). Further, decreasing concern for climate change among the American public has been documented over the past few years (Gallup, 2010a, 2010b).

Budget Items

More than half of the students responded incorrectly on all but one budget question in the first year’s survey (Fig. 2.4). Graphical questions had the lowest percentage of correct student answers, with only 9% answering Q5, and 2% answering Q6 correctly. The highest percentage of correct responses (61%) was observed on Q3 where students recognized atmospheric carbon levels would be stable when inputs
remained equal to outputs. The distribution of correct answers on the second year’s survey (Fig. 2.5) was remarkably similar to that observed in (Fig. 2.4) indicating that although some differences between the two years’ students existed, their knowledge of budgets was almost identical.

**Figure 2.3:** Student performance on budget questions in first year of sampling period. The majority of students answered questions incorrectly except for Q3. Performance is particularly low for graphical questions Q5 and Q6.

**Figure 2.4:** Student performance on budget questions in second year of sampling period. Results were similar to those observed in first year.
Opinion of climate change seriousness and understanding of consensus

Though there were some significant differences between the two groups, most participants indicated that they thought global climate change was a serious issue (see Table 2.3) by selecting “somewhat serious” (42%) or “very serious” (35%). When students reflected on the scientific consensus for climate change, 67% had the correct perception of it (Figure 2.4). A considerable percentage of students were under the impression there is significant scientific debate about climate change occurring (22%), or that there are insufficient data for scientists to assess climate change (9%). Importantly, no significant differences in budget knowledge were observed among students who held different opinions of the seriousness of climate change or among students who held differing levels of understanding of the scientific consensus for climate change.

Table 2.3: Percentage of students who chose one of 5 statements that most agreed with their opinions regarding the seriousness of climate change.

<table>
<thead>
<tr>
<th>Statement regarding seriousness of climate change</th>
<th>1st year (n = 482)</th>
<th>2nd year (n = 465)</th>
<th>Overall (n = 947)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very serious</td>
<td>40.66%</td>
<td>28.88%</td>
<td>34.88%</td>
</tr>
<tr>
<td>Somewhat serious</td>
<td>41.08%</td>
<td>43.97%</td>
<td>42.49%</td>
</tr>
<tr>
<td>Not very serious</td>
<td>8.51%</td>
<td>13.36%</td>
<td>10.89%</td>
</tr>
<tr>
<td>Not a problem</td>
<td>3.94%</td>
<td>8.62%</td>
<td>6.24%</td>
</tr>
<tr>
<td>Don’t know</td>
<td>5.81%</td>
<td>5.17%</td>
<td>5.50%</td>
</tr>
</tbody>
</table>

Note: P-value for comparing difference between years of sampling period is less than 0.001. No significant differences were found in levels of budget knowledge and opinion of climate change.
Figure 2.5: Percentage of students picking one of 4 statements that most agreed with their understanding of scientific consensus for climate change.

Note: No significant difference in budget knowledge was found among differing levels of students’ understanding of the consensus for climate change.

Interest in Science

Recall that differences existed between the two years of the sampling period with regard to students’ interest in science. Science interest levels are presented in Table 2.4. To address this difference, the effects of analyses of science interest on budget knowledge were conducted separately for each year. For each year of the sampling period a 1x3 ANOVA was conducted with level of science interest (neutral or less, somewhat, or very interested) as the independent variable and budget knowledge as the dependent variable. For the first year, a main effect was found for level of science interest
Table 2.4: Percentage of students who chose one of five levels to indicate science interest. P-value for comparing difference between years of sampling period is less than 0.001.

<table>
<thead>
<tr>
<th>Level of science interest</th>
<th>1st year (n = 482)</th>
<th>2nd year (n = 465)</th>
<th>Overall (n = 947)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very interested</td>
<td>23.70%</td>
<td>17.64%</td>
<td>20.72%</td>
</tr>
<tr>
<td>Somewhat interested</td>
<td>45.12%</td>
<td>36.77%</td>
<td>41.02%</td>
</tr>
<tr>
<td>Neutral</td>
<td>20.37%</td>
<td>26.88%</td>
<td>23.57%</td>
</tr>
<tr>
<td>Not very interested</td>
<td>09.98%</td>
<td>15.05%</td>
<td>12.47%</td>
</tr>
<tr>
<td>No interest at all</td>
<td>00.83%</td>
<td>03.66%</td>
<td>02.22%</td>
</tr>
</tbody>
</table>

with those who were more interested exhibiting greater budget knowledge \( (F_{(2, 479)} = 17.04, p<.001) \); for the second year, a similar main effect was found for level of science interest \( (F_{(2,462)} = 15.19, p<.001) \). Thus, despite the two years’ differences in science interest, the main effect of science interest on budget knowledge was essentially the same for both years (Table 2.5).

Table 2.5: Effect of level of science interest on budget knowledge for two years of sampling period.

<table>
<thead>
<tr>
<th>Science interest</th>
<th>1st year mean</th>
<th>2nd year mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very interested</td>
<td>2.31</td>
<td>2.27</td>
</tr>
<tr>
<td>Somewhat interested</td>
<td>1.76</td>
<td>1.78</td>
</tr>
<tr>
<td>Neutral or less</td>
<td>1.44</td>
<td>1.50</td>
</tr>
</tbody>
</table>

Gender

Aside from science interest, the only other demographic predictor variable that reached significance—once the Bonferroni correction was made—was gender. A two sample t-test revealed an effect for gender \( (p<.001) \). Males \( (M=1.94) \) scored higher on the budget knowledge answers than did females \( (M=1.59) \).
Discussion

The majority of students surveyed did not seem to recognize that emission rates of carbon would have to drop below removal rates from the atmosphere in order to decrease the carbon concentration in the atmosphere (Q1). Such thinking suggests that students are under the impression climate change is easily reversible, some students perhaps thinking that maintaining emission rates at their current level is sufficient to stop the rise in atmospheric greenhouse gases (i.e. if emission rates stop increasing so will overall carbon levels). This “pattern matching” behavior has been identified in other studies (Sterman, 2008; Sterman and Booth Sweeney, 2007; Cronin et al., 2009). Our findings show that over 80% of students in 2008 and over 90% of students in 2009 matched the point of highest (lowest) emissions with maximum (minimum) atmospheric carbon concentration when examining a graph of emissions and natural carbon removal.

Although carbon budget misconceptions exist, the majority of students surveyed (77%) felt that global climate change was a serious or a somewhat serious problem. The mismatch in students’ concern for climate change and their understanding of some of its crucial aspects could present interesting motivational opportunities for educators. Curiosity, or the desire for knowledge and intellectual achievement, has been identified as a key motivator for student learning (e.g. Maslow, 1970; Reiss, 2004), which suggests that increased motivation could result from making students aware of their misunderstandings of budgets and stimulating students’ desire for deeper knowledge and understanding about a topic that many students find to be at least somewhat concerning. Other researchers have suggested a link between environmental concern and information
seeking efforts resulting in increased knowledge about global warming (Kahlor & Rosenthal, 2009).

Students’ understanding of atmospheric carbon budgets was not impacted by how serious they thought climate change was or their understanding of the scientific consensus for climate change. This suggests that budget misunderstandings are poorly understood in general, even by those who may support a reduction in emissions but may not understand why such reductions are needed. Our results reinforce the findings of other studies showing fundamental misconceptions of budgets held by the general public, as similar misunderstandings are found among highly educated adults (e.g. Sterman and Sweeney, 2007). Results of this study suggest that budget misunderstandings might be persistent regardless of a person’s political stance on climate change. Although political affiliation was not indicated on our survey, others have shown that views regarding the seriousness of climate change—which were examined in this study and found not to be correlated with knowledge—are sharply divided by political affiliation (Gallup, 2010b).

After analyzing our data to identify demographic predictors of budget knowledge, only two variables were found to be significant: interest in science and gender. These two variables likely have some level of dependence on one another. For example, of the students surveyed, only 14% of females reported being very interested in science, while nearly twice as many males—27%—reported this. Such gender differences likely reflect societal attitudes and experiences toward and of science that become indoctrinated early on in children (Jones, Howe & Rua, 2000). Males and people interested in science are more likely to have engaged in physical science activities in their lifetimes, some
activities of which were likely to have dealt with the law of conservation of mass or similar concepts, and thus these individuals have developed a better understanding of budgets.


Conclusions

A survey completed by 947 students in introductory geology courses reinforces findings showing widely held misconceptions of applications of mass balance as it relates to carbon in the atmosphere. The level of budget misunderstanding significantly varies with the demographic backgrounds of gender and science interest. Males had greater budget knowledge than did females, and those more interested in science (often also males) tended to have greater budget knowledge.

Budget understandings across all demographic variables were poor and misunderstandings were amplified when students tried to interpret graphical data. Poor graphical interpretation is likely related to students matching overall stock levels in a system with the inflow levels to that system. In a sense, students were visually misled when they examined an inflow-outflow graph and confused the highest rates of inflow with maximum stock levels and lowest rates of inflow with minimum stock levels. Such misunderstandings of budgets, a fundamental application of the law of conservation, demand remediation because so many applications of this fundamental idea exist. The very poor graphical understanding demonstrated by students also needs to be specifically targeted for remediation since complex data sets (such as budgets) are frequently presented in graphical formats.

Budget misunderstandings and misconceptions documented in this study suggest a pressing need to remedy them specifically within the geosciences. Students exposed to budget concepts in introductory geoscience courses and the general public would benefit from a better understanding of stock-and-flow relationships and their multiple practical
applications. Geoscience majors will encounter these systems as they learn, for example, about glacial mass balance, sediment storage in fluvial systems, and water storage and extraction from aquifers.
References


Gallup, (2010b) March 4-7, 2010 Poll. Available on Gallup’s website: 


CHAPTER 3: Misunderstanding atmospheric carbon budgets: A case study to teach students the law of conservation of mass

A paper in preparation for submission to the International Journal of Environmental and Science Education.

Collin Reichert, Cinzia Cervato, Michael Larsen and Dale Niederhauser

Abstract

This paper describes a case study designed to remediate atmospheric carbon budget misunderstandings and misconceptions identified and described in the paper by Reichert, Cervato, Larsen and Niederhauser (submitted – this journal). This study is based off of one year’s data collected from a survey completed by introductory physical geology students (n = 465) including a control group (n = 399) and an experimental group (n = 66). The students in the experimental group worked on a remediation assignment targeting identified misconceptions during a laboratory session. After students completed the remediation assignment, which was designed to challenge the students’ specific areas of misunderstanding, significant learning gains and misconception reductions were observed.
Introduction

As described in Reichert et. al. (submitted), undergraduate students surveyed at Iowa State University demonstrate poor understanding of budget (or stock-flow) systems, specifically atmospheric carbon budgets. These misunderstandings lead many students to think that stock levels are controlled solely by the inflow to a system, especially when the inflow/outflow rates are presented to students graphically (this particular misunderstanding will herein be referred to as “pattern matching”). Therefore, many undergraduate students likely and wrongly believe that simply stabilizing carbon dioxide emissions at their current levels would stop the increase of atmospheric CO₂.

Understanding budget systems is crucial for many reasons, including managing personal finances. In particular, an understanding of atmospheric carbon budgets is important for the general public to be able to address climate change and to understand the scientific foundations of the problem. The misunderstandings of budgets are not limited to undergraduate students as shown in Reichert et. al. (submitted); they persist even among highly educated graduate students at prestigious universities such as MIT (e.g., Sterman & Booth Sweeney, 2007).

A variety of approaches have been developed to teach the scientific principles of climate change to post-secondary students. Researchers have advocated the implementation of constructivist learning principles when teaching climate change (Meadows & Wiesenmayer, 1999; Huntoon & Ridky, 2002; Rebich & Gautier, 2005; Bardsley & Bardsley, 2007; Harrington, 2008; McCaffrey & Buhr, 2008; Moxnes & Saysel, 2009) as well as the incorporation of andragogy (adult education) principles (Arndt & Laude, 2008; Schuster, Fillippelli & Thomas, 2008). In addition to these
learning principles, the study described here used principles recommended by cognitive flexibility theory (Spiro, Coulson, Feltovich & Anderson, 1988).

**Pedagogical Foundation of this Study**

Constructivist learning theory has been greatly influenced by the work of Jean Piaget (1963). Piaget held that knowledge is generated by the creation of mental representations of the world, or schemas, that change through time based on an individual’s experiences (Piaget, 1963; Driver, Asoko, Leach, Mortimer & Scott 1994; Woolfolk, 2007). According to Piaget, individuals undergo a continuous attempt at equilibration, or testing schemas’ adequacy in explaining what a person experiences. Experiences can either be explained by an existing schema, a process called assimilation, or if they cannot be adequately explained by an existing schema (and the experience is not dismissed as invalid), the person must go through the process of adaptation, in which the schema is changed or replaced to fit the new information (Piaget, 1963; Woolfolk, 2007).

In this study, after having identified students’ misconceptions (inappropriate schemas), we attempted remediation by presenting students with information that could not possibly be explained by their existing mental schemas. Ideally, students would then adapt their inadequate schemas. The process of having students investigate information specifically challenging their misconceptions is known as cognitive conflict and has also been recommended in teaching climate change (Meadows & Wiesenmayer, 1999; McCaffrey & Buhr, 2008). Conceptual change in students is by no means easy as incorrect science ideas may persist among people who already have engaged in cognitive
conflict. Of critical importance to conceptual change is that students who have incorrect scientific ideas are not only challenged on those ideas but also presented with an intelligible replacement (preferably one that is scientifically accurate!) (Scott, Asoko & Driver, 1991).

A traditional emphasis in educational research has focused on the way children learn, but some research has also described the differences between the instruction children should receive (pedagogy) and the instruction adults should receive (andragogy). Knowles, Holton and Swanson (2005) have laid out the basic principles of how adults learn and several of those principles were followed in this study: students must be able to call on prior experience, concepts being taught must have some relation to real-life, and learners prefer to learn through problem-solving.

Students exposed to an introductory level understanding of a particular subject area often demonstrate an inability to transfer knowledge learned to new or more complex scenarios (Spiro et al. 1988). Because of this inability, cognitive flexibility theory advocates a case-based learning environment, which provides students with novel and ill-structured problem-solving tasks. Cognitive flexibility theory attempts to endow students with the skills associated with advanced knowledge acquisition, namely the complexity of content and its applicability in other domains. The main principles of cognitive flexibility theory outlined by Spiro et al. (1988) are: a) avoiding oversimplification of content by creating complex, ill-structured learning domains; b) using multiple representations of content so different applications of the concept are made; c) using cases to teach the concept (avoiding abstract representations); d) making
multiple interconnections between cases that exemplify the content; and e) knowledge must be constructed by the learner, not transmitted by the instructor.
Method

As described in Reichert et. al. (submitted), students in an introductory physical geology course over the course of a two year sampling period completed a survey within the first two weeks of the semester. In the second year, the surveyed class was split into a control group consisting of 399 students only enrolled in the lecture portion of the geology class, and an experimental group consisting of 66 students enrolled in the lecture and an accompanying, unrequired, laboratory course. This study is based solely on the data collected of the students enrolled during this second year.

Students provided demographic information on the survey including gender, age, college in which they are majoring, year in school, mother’s and father’s level of education, interest in science, concern for the environment, and level of environmental action (students reported whether they partook in any of 8 actions listed such as recycling, energy conservation, water conservation, etc.—students were coded with low environmental action levels if they partook, at least sometimes, in 0 to 2 actions; medium environmental action levels if they partook in 3 or 4 actions, and high environmental action if they partook in 5 or more actions). The survey also served as a pretest assessment of student knowledge of atmospheric carbon budgets based on 6 budget questions students answered. The six atmospheric budget questions asked on the survey required students to: recognize emissions would have to drop below removal rates in order to decrease atmospheric carbon levels (Q1); examine a textually described scenario of emissions and carbon removal rates to determine when decreasing, stable, and maximum atmospheric carbon levels would occur (Q2, Q3, and Q4, respectively); and
examine a graph of emissions and carbon removal to determine points at which maximum or minimum carbon levels would occur (Q5 and Q6, respectively).

Initial analysis of survey responses indicated that many students seemed unable to generalize budget concepts. Assuming students would generalize knowledge using multiple and different representations of budget concepts, we developed a case study that addressed the key misunderstandings identified through the surveys. We chose an online—and at the time, under development—problem-solving e-learning domain as the environment to host the assignment: ThinkSpace\(^4\).

The budget assignment consists of a hypothetical scenario in which students take on the role of a local snow-cone business owner. Students completed four budget tasks involving a sink model with faucet and drain, radiation budgets in the atmosphere, a hypothetical bank account, and atmospheric carbon budgets.

As the business scenario deals with producing an edible product, students are instructed in the first task to meet health code requiring utensils to be stored in a container with continuously flowing sanitary fluids. The business is equipped with a sink and variable input rates on the faucet (0.0 L/hr to 10.0 L/hr) but a constant output in the drain (1.0 L/hr). Students go about maintaining the inflow rate at levels that would allow water in the sink to reach a maximum level of 70 liters.

To accomplish this task, students could access a simulation (Fig. 3.1) for the sink (the same used in a meteorology course to allow students to investigate radiation budgets

\(^4\) A screencast of the assignment is available at: http://screencast.com/t/MTI4MDQzM. Full access and use of the assignment is possible by contacting Cinzia Cervato at cinzia@iastate.edu.
and described in Reichert, Cervato and Larsen (submitted)\textsuperscript{5}. In the simulation, students control the inflow rate during business hours (6 AM to 6 PM) by adjusting the inflow $\pm$ 2.0 L/hr at the top of every hour. Graphs in the simulation record inflow and outflow rates and overall water levels for a 24 hour period. When the simulation is completed, students interpret the simulation data by answering a series of multiple choice questions. In the second task students maintain inventory by determining yearly variation of temperature and assuming that snow-cone sales are correlated with it (i.e. higher temperatures result in higher sales). Students read a brief explanation of the connection of temperature with radiation budgets and navigate through relevant and irrelevant resources to determine yearly radiation and temperature variation for their location. The resources students may access include radiation and temperature graphs, climate data from the National Climate Data Center, and an animation depicting the axis orientation of Earth as it orbits the Sun. Again, students answered a series of multiple-choice questions based on this scenario; these questions were almost identical to those asked in the first task except for the change in budget topic.

The third task requires students to consider their business’s financial situation and the timing of renovations planned for the snow-cone shop. Bank account records are presented in tables and graphs for the past year’s income and expenses. The graphs presented dollar amounts for deposits, withdrawals, and a running balance over the course of a year. The aim

\textsuperscript{5} The budget simulation program is available online at http://www.pals.iastate.edu/simulations/library/budgetsim/index.html
of the third task was to explicitly address a pattern-matching misconception many students held. To do this, and to test the effect of cognitive conflicts in teaching budget concepts, about half of the students (n = 32) in the experimental group were presented with a cognitive conflict in the third (Fig. 3.2) and fourth tasks. The cognitive conflict challenged the association of maximum inflow rates with maximum overall levels and students were asked to construct a response explaining the maximum point in bank balance. The students who did not engage in cognitive conflicts were instead provided with an emphasized statement explaining the bank graph.

**Figure 3.1** Simulation used by students in remediation assignment. Students adjust inflow rate during business hours and graphs record data for a 24 hour period. Students answer questions requiring interpretation of data recorded by the graphs on the right.

In the fourth task students projected future sales for the 21st century assuming correlation between snow-cone sales and projected temperature increases. Students also
considered whether a capacity for expansion would exist due to market enlargement. This task included many resources, the majority coming from the 2007 Intergovernmental Panel on Climate Change’s report and projections (IPCC, 2007). Students considered the effect of a 20%-40% reduction in emissions on atmospheric carbon levels. The cognitive conflict in this task required students to construct a response explaining why during a period of stable emissions in the 1990’s, greenhouse gas concentrations continued to rise. Students also constructed responses as they considered emission scenarios generated by the IPCC (2007) and the implications for temperature throughout the 21st century. Students accessed a resource containing a graph of the A2, A1B and B1 emission scenarios and carbon removal projected at its current value (Fig. 3.3).

![Graph of Inflow and Outflow](image1)

**Figure 3.2:** Bank account records presented to students. Half of the experimental group was asked to explain why the maximum balance occurs in October when maximum deposits are in July (cognitive conflict) and the other half was simply given a statement explaining this situation.
This graph shows three of the scenarios developed by the IPCC for future greenhouse gas emissions in the 21st century. The removal of carbon from the atmosphere by oceans, plant-life and other factors currently absorbs about 50% (4 billion tons/yr) of the current emissions (8 billion tons/yr). Scientist think that the ability of natural sources to absorb carbon from the atmosphere will decrease over time, but here it is represented as constant.

**Figure 3.3:** Graph and caption students could access when examining atmospheric carbon budgets.

The administration of the assignment occurred during a 2-hour lab period. Four lab sections participated in the assignment which was carried out in a computer lab in groups of 2-3 students and followed a 15-minute presentation on glaciers, current global glacier retreat, and an example of glacier mass balance including the causes of glacial advancement and retreat (accumulation and ablation balance). The senior author was present for assistance with technical issues of the assignment and provided occasional encouragement to students. Upon completion of the assignment, students answered a short questionnaire in which they interpreted a graph presenting a glacial mass balance problem and provided general feedback on the assignment.
When the lecture class (which included the control and experimental group) covered climate change, information and the graph used on the survey were explained to students through a lecture. At the end of the semester, within two weeks of the experimental group’s completion of the remediation assignment, students in the class answered 5 budget questions taken from the survey on their final exam (Q1, Q2, Q4, Q5 and Q6). Data from the final exam were collected electronically by a Scantron® reader, and manually matched by name and student ID number to the survey data.

**Statistical methods**

Standard errors and means were computed for group scores (e.g., number of correct answers). Groups were defined by categorical variables identified from the survey, such as gender (female/male), age (age groups), college, parents’ education (education levels for father, mother, or highest overall parents’ education), and response to questions on concern for the environment, interest in science, and level of environmental action (high/medium/low). Two sample t-tests and one-way analysis of variance (ANOVA) were used to assess statistical significance. Multiple linear regression was used to assess the relationship between a quantitative outcome and multiple variables. Multiple categorical predictor variables were represented as sets of indicator variables. Interactions were entered into the model by multiplying sets of indicator variables. F-tests were used to assess significance for sets of indicators variables. When an outcome was binary or ordinal with a small number of categories, chi-squared tests were used to assess the hypothesis of independence from categorical predictor variables.
Results

The overwhelming majority of students (50 of 66) assigned to the experimental group were enrolled in the College of Liberal Arts and Sciences (LAS), whereas the rate was less than half in the control group (146 of 399) and so analysis and comparisons between groups are reported both for the entire sample and restricted to students in this college. Students in the experimental group had a mean score of 3.18 (SD = 1.58; M=3.36 in LAS; SD = 1.57 in LAS) for environmental actions taken, significantly more than the control group (Overall: M=2.38; SD = 1.67; T (463) = 3.63; p<0.001. LAS: M=2.25; SD = 1.60; T(194) = 4.27, p<0.001). The experimental group also had a significantly higher interest in science than the control group (see Table 3.1) and a significantly greater percentage of students who identified themselves as concerned for the environment. The experimental group had fewer freshmen and seniors but more juniors than the control group; the distribution of college year between the two groups, however, was not significantly different.

The experimental group (mean 2.29, SD 1.15; LAS mean 2.30, SD 1.20) scored significantly higher (T(463) = 4.42;p<0.001; LAS only T(194) = 3.05; p=0.003) than the control group (mean 1.64, SD 1.09; LAS mean 1.73, SD 1.13). Scores ranged from 0 to 6. One can adjust for group differences with a linear model. A linear model was fit using group (experimental versus control), gender, college, year (4 levels), interest in science (3 levels), concern for the environment (3 levels), and degree of environmental action (3 levels). Backward and forward selection based on the AIC criterion was used to eliminate or add variables. Variables for gender, science interest, environmental concern, college and group are significant predictors of score. Backward and forward selection based on
the AIC criterion was used again to consider interactions between pairs of selected variables. Interactions between gender and both science interest and environmental concern are added to the model as significant predictors.

Table 3.1: Demographic differences between control and experimental student groups. Differences are reported for all students and restricted to students enrolled in the Liberal Arts and Sciences College (LAS).

<table>
<thead>
<tr>
<th></th>
<th>Very concerned about Environment</th>
<th>Somewhat concerned</th>
<th>Neutral to Not at all concerned</th>
<th>( X^2; ) DF=2; Pvalue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (n=399)</td>
<td>19%</td>
<td>53%</td>
<td>28%</td>
<td>( X^2=9.54, ) pvalue=0.008</td>
</tr>
<tr>
<td>Experimental (n=66)</td>
<td>33%</td>
<td>53%</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>LAS only</td>
<td></td>
<td></td>
<td></td>
<td>( X^2=12.2; ) pvalue=0.002</td>
</tr>
<tr>
<td>Control (n=146)</td>
<td>20%</td>
<td>47%</td>
<td>33%</td>
<td></td>
</tr>
<tr>
<td>Experimental (n=50)</td>
<td>34%</td>
<td>54%</td>
<td>12%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Very interested in science</th>
<th>Somewhat interested</th>
<th>Neutral to Not at all interested</th>
<th>( X^2; ) DF=2; Pvalue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (n=399)</td>
<td>13%</td>
<td>38%</td>
<td>49%</td>
<td>( X^2=37.7, ) pvalue&lt;0.001</td>
</tr>
<tr>
<td>Experimental (n=66)</td>
<td>44%</td>
<td>30%</td>
<td>26%</td>
<td></td>
</tr>
<tr>
<td>LAS only</td>
<td></td>
<td></td>
<td></td>
<td>( X^2=19.1; ) pvalue&lt;0.001</td>
</tr>
<tr>
<td>Control (n=146)</td>
<td>11%</td>
<td>32%</td>
<td>57%</td>
<td></td>
</tr>
<tr>
<td>Experimental (n=50)</td>
<td>36%</td>
<td>34%</td>
<td>30%</td>
<td></td>
</tr>
</tbody>
</table>

Students in the experimental group performed better on average than the control group on budget questions (Fig. 3.4 and Table 3.2). The experimental group’s better survey performance appears limited to lower-level cognitive questions (such as recognizing that higher CO\(_2\) inflow than CO\(_2\) outflow results in increasing CO\(_2\) levels—
Q1, Q2 and Q3). Experimental group performance is similar to the control groups’ performance for higher-level cognitive questions (such as recognizing the conditions leading to maximum and minimum CO₂ levels—Q4; and graphical interpretation—Q5 and Q6).

Figure 3.4: Results of survey budget questions by group assignment. Experimental group performance is better than the control group’s for all but one question. Differences are mostly apparent for lower cognitive level questions (Q1, Q2, and Q3) as performance on higher cognitive level questions (Q4, Q5, and Q6) is more similar among groups.

Table 3.2: Pretest survey score comparison between experimental and control group. Scores are reported for all students and restricted to students enrolled in the Liberal Arts and Sciences College (LAS).

<table>
<thead>
<tr>
<th></th>
<th>All cases</th>
<th>Fisher’s exact test</th>
<th>LAS only</th>
<th>Fisher’s exact test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Experimental</td>
<td>pvalue</td>
<td>Control</td>
</tr>
<tr>
<td>Q1</td>
<td>38%</td>
<td>56%</td>
<td>0.007</td>
<td>45%</td>
</tr>
<tr>
<td>Q2</td>
<td>37%</td>
<td>62%</td>
<td>&lt;0.001</td>
<td>36%</td>
</tr>
<tr>
<td>Q3</td>
<td>58%</td>
<td>79%</td>
<td>0.001</td>
<td>58%</td>
</tr>
<tr>
<td>Q4</td>
<td>23%</td>
<td>24%</td>
<td>0.76</td>
<td>25%</td>
</tr>
<tr>
<td>Q5</td>
<td>6%</td>
<td>8%</td>
<td>0.57</td>
<td>5%</td>
</tr>
<tr>
<td>Q6</td>
<td>4%</td>
<td>0%</td>
<td>0.14</td>
<td>3%</td>
</tr>
</tbody>
</table>
Experimental group performance on the remediation assignment is presented in Figure 3.5 and 3.6. The percentage of correct responses to graphical interpretation questions increases by question (Fig. 3.5) so students seemed to improve their graphical interpretation skills as they worked through the assignment. Performance on the final question of the remediation assignment, however, drops.

When comparing performance based on whether students were engaging in cognitive conflicts or not, similar performance was observed throughout the assignment, except for Task 3 (which required an answer from only the half of the experimental group engaged in cognitive conflict). Though the performance on the remediation assignment suggests little difference in the use of cognitive conflicts, results of the questionnaire students completed immediately following the remediation assignment reveal a substantial difference between the cognitive conflict and non-cognitive conflict groups (Fig. 3.7). Students who did not engage in cognitive conflicts have a significantly higher number of students who still hold the pattern matching misconception (as identified from glacial ablation questions on the questionnaire) than do students who engaged in cognitive conflicts. The level of maximum pattern matching (matching the highest inflow point on a graph with highest stock level) for the cognitive conflict group was slightly more significantly different from the group without cognitive conflicts $[\chi^2(3, N = 64) = 10.43, p = 0.02]$ than minimum pattern matching (matching lowest inflow point on a graph with lowest stock level) $[\chi^2(3, N = 64) = 9.04, p = 0.03]$. 
Figure 3.5: Student performance on graphical interpretation questions throughout the course of the remediation assignment. Questions 3 and 4 were included in Task 1; questions 7 and 8 were included in Task 2; *question 9 was included in Task 3 of the remediation assignment and only half of the experimental group students had to construct a response for this question; question 12 was included in Task 4 and required students to apply budget knowledge to atmospheric carbon. It appears that performance on graphical interpretation questions increases as students work through the assignment, but performance drops once again on question 12.
Figure 3.6: Average percentage of correct responses to questions in each remediation assignment task. Students examined water budgets of a simulated sink in Task 1, radiation budgets and their effect on temperature variation in Task 2, bank account balance in Task 3 and carbon budgets in Task 4.* Task 3 performance is based on data from only the half of the experimental group that engaged in cognitive conflicts, the other half did not have to construct a response in Task 3 but were asked an additional question in Task 4 to make up some of the time on task.
Pattern-matching misconception level among experimental group students observed on questionnaire

Figure 3.7: Percentage of students identified as holding a pattern matching misconception on the questionnaire completed immediately following the remediation assignment. Significantly lower numbers of students held the misconception when they engaged in cognitive conflicts during the remediation assignment.

The difference observed in pattern matching misconceptions levels among students who engaged in cognitive conflicts and those who did not is at first glance still apparent on the final exam (Fig. 3.8); however, these differences are no longer statistically significant ($p = 0.39$ for maximum pattern matching and $p = 0.36$ for minimum pattern matching). For comparison, Figure 3.8 shows pattern matching levels of the experimental group for various points in the semester. Misconception levels were
identical across the experimental group on the pretest survey but differences appear following the remediation assignment.

**Figure 3.8:** Effect of cognitive conflicts on decreasing the pattern-matching misconception among experimental group students. The number of students in the experimental group that held the pattern matching misconception was identical on the pretest survey for the group that engaged in cognitive conflicts and the group that did not. Significant differences were observed immediately following the remediation, with those who engaged in cognitive conflict holding the pattern matching misconception less than those who did not engage in cognitive conflict. There were some differences observed on the final exam but these were not statistically significant given the sample size.

When the level of pattern matching misconceptions for the experimental group as a whole are compared to the control group it is apparent that the drop in percentage of
students holding the pattern matching misconceptions is greater for the experimental group than for the control group (Fig. 3.9). Reduction in the number of students holding the pattern matching misconception on the final exam was significant for the control group when looking at maximum pattern matching misconception levels on the final exam \( \chi^2 (3, N = 368) = 23.55, p < 0.001 \) but not when looking at minimum pattern matching misconception levels on the final exam \( \chi^2 (3, N = 368) = 5.21, p = 0.16 \). The reduction in misconception levels for the experimental group, on the other hand, is significant for both types of pattern matching misconceptions on the final exam (maximum: \( \chi^2 (3, N = 64) = 129.1, p < 0.001 \); minimum: \( \chi^2 (3, N = 64) = 73.56, p < 0.001 \).
Figure 3.9: Differences in reduction of pattern matching observed in the control and experimental group for students who completed the final exam. Q5 required students to interpret maximum CO$_2$ levels from a graph while Q6 required students to interpret minimum CO$_2$ levels. Significant reduction in misconceptions was observed on the final exam for the control group on Q5 but the reduction is not significant for Q6. Reduction of misconceptions observed on the final exam is significant for the experimental group on both Q5 and Q6. Students who did not take the final exam were removed from these comparisons.

Students in the experimental group outperformed control group students on all of the final exam budget questions. Only 2 (one in LAS, one not in LAS) of the 66 (3.0%) experimental group students did not take the final exam, whereas 33 (18 in LAS, 15 not in LAS) of the 399 (8.2%) in the control group did not take the final exam; the Fisher exact test p-value for comparing these proportions is 0.20, which is not statistically significant.

We observed improvements in budget understanding on all five final exam budget questions in the experimental group and only 3 questions in the control group (Fig. 3.10). Using McNemar’s test for correlated proportions in the marginals of a 2x2 contingency table, the increases in the control group on questions 1, 2, and 5 are statistically significant with p-values less than 0.001, whereas the decrease in question 6 is statistically significant with a p-value of 0.004. In the experimental group, the p-values for questions 1, 2, 4 and 5 are less than 0.001, 0.44, 0.010, and 0.001, respectively.

A composite score is formed by counting the number of correct answers to the five posttest questions. Table 3.3 contains pre and post mean scores for control and experimental groups. In all cases, the increase in score is statistically significant with p-value less than 0.001. P-values are computed using one sample matched pair samples. The difference in improvement between the experimental group (mean change 1.03; SD
1.11; LAS only mean change 0.94; SD 1.14) and the control group (mean change 0.64; SD 1.15; LAS only mean change 0.52; SD 1.11) is statistically significantly higher (difference 0.39; T(430) = 2.50; p=0.01; LAS only difference 0.42; T (175) = 2.21; p = 0.03). Thus, despite having higher initial scores on average, the experimental group improved significantly more than did the control group.

Adjusting scores on the final exam for differences in pretest score, gender, environmental action, interest in science, environmental concern, College, and year in school still results in a significant difference in scores between groups observed on the final exam. Other things being equal, in the final regression model, which included pretest score, interest in science, an interaction between pretest score and interest in science, and group, the experimental group members on average did 0.52 points better on the final exam (p<0.001).

Performance on the final exam restricted to LAS students is reported in Figure 3.11. Scores for the LAS experimental group with pvalue for comparison to pretest percentages given in parentheses were: Q1, 92% (p<0.001); Q2, 67% (p=0.83); Q4, 43% (p=0.10); Q5, 39% (p<0.001); and Q6, 8% (0% correct on pretest). Scores for the LAS control group with pvalue for comparison to pretest percentages given in parentheses were: Q1, 84% (p<0.001); Q2, 45% (p=0.18); Q4, 25% (p=0.87); Q5, 15% (p=0.004); and Q6, 1% (p=0.48).
Figure 3.10: Differences in improvement on budget questions observed for the control group (top graph) and experimental group (bottom graph). Although pretest scores were higher with the experimental group to begin with, statistical analysis adjusted for other factors influencing score revealed the experimental group improved significantly more than control group. Graphical interpretation on Q5 in particular has improved more in the experimental group than control.

Table 3.3: Composite scores comparing pre and post mean scores between experimental and control groups for all students and restricted to students enrolled in the LAS College.

<table>
<thead>
<tr>
<th># correct on 5 questions</th>
<th>Pretest mean</th>
<th>Pretest SD</th>
<th>Posttest mean</th>
<th>Posttest SD</th>
<th>T value</th>
<th>DF</th>
<th>Pvalue for pre-post change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td>1.07</td>
<td>0.94</td>
<td>1.71</td>
<td>0.97</td>
<td>10.73</td>
<td>367</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Experimental group</td>
<td>1.50</td>
<td>1.04</td>
<td>2.50</td>
<td>1.11</td>
<td>7.42</td>
<td>63</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Control in LAS</td>
<td>1.14</td>
<td>0.95</td>
<td>1.70</td>
<td>1.00</td>
<td>5.34</td>
<td>127</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Experimental in LAS</td>
<td>1.56</td>
<td>1.07</td>
<td>2.49</td>
<td>1.16</td>
<td>5.74</td>
<td>48</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Figure 3.11: Percentage of LAS students answering final exam budget questions correctly. Students in the experimental group had higher average scores on the pretest but still improved significantly more on the final exam than did the control group.
Discussion

The final exam results show improvement in budget understandings without specific remediation in student performance on lower cognitive level budget questions (i.e. questions asking students to determine what conditions of inflow and outflow lead to increasing, decreasing, or stable stock levels—Q1, Q2, and Q3); however, large improvements in higher cognitive level questions (i.e. questions asking students to determine the conditions of inflow and outflow leading to maximum and minimum stock levels—Q4, Q5, and Q6) were only observed after explicitly addressing student misunderstanding through the remediation assignment.

The initial assessment of the effectiveness of the remediation assignment is encouraging. Many students who held the pattern-matching misconception on the pretest did not revert to it when answering the assignment questionnaire or final exam questions. The experimental group also significantly outperformed the control group on the final exam questions even when other factors affecting score are considered. These results suggest that students are able to generalize knowledge when they navigate through multiple representations of a concept in a real-world context. The general trend showing improvement in graphical interpretation questions throughout the course of the remediation assignment also lends credibility to its effectiveness, though there is an inconsistency as the average performance on the final graphical interpretation question is poor.

There are some concerns regarding the effectiveness of the particular remediation strategy used here. The percentage of experimental group students holding the pattern-matching misconception increases from the time students complete the remediation
assignment until they take the final exam. Although misconception levels are still lower on the final exam than on the survey, students may be reverting back to the pattern-matching misconception, which suggests that this misconception is deeply ingrained. Just because the pattern matching misconception is not apparent does not mean that students are answering the questions correctly, it means that students are not simply matching the highest inflow point with highest stock levels or lowest inflow point with lowest stock level. This distinction is important because many students in the experimental group still perform quite poorly on one of the graphical interpretation questions asked on the final exam. The drop in misconceptions could indicate that students are beginning to recognize the complexity of an inflow-outflow graph.

Students in the experimental group performed better on graphical interpretation of maximum stock levels (Q5) than they did on graphical interpretation of minimum stock levels (Q6) on the final exam; in fact, experimental group performance was quite poor on Q6. So, the vast majority of experimental group students still did not generalize knowledge of budgets completely. Students in the experimental group were able to more correctly interpret maximum levels from a budget graph but did not apply the very same knowledge when interpreting a minimum value on the same graph. This unequal performance may be a result of the remediation assignment requiring students to examine primarily maximum stock levels in the various budget scenarios. Future instruction could benefit from use of scenarios in which both maximum and minimum stock levels are examined as well as provide students with multiple cognitive conflicts addressing students’ misconceptions in multiple ways (i.e. provide cognitive conflicts to address
minimum inflow association with minimum stock level in addition to maximum inflow with maximum stock level).
Conclusions

It appears that budget misconceptions cannot be effectively reduced by relying on lecture presentations alone, as often might be done in introductory science courses. When students engage in an ill-structured, real-world case study with multiple representations of budget scenarios challenging budget misconceptions, significant learning gains are made and there are noticeable drops in misconceptions held by students on graphical interpretation questions. Learning gains and misconception reductions are most apparent when student misunderstandings are explicitly challenged with cognitive conflicts requiring students to wrestle with information they can only explain when mass-balance concepts are understood.

The results of this study lead us to conclude, generally, that students can learn budget concepts when time on task is increased and when students view concepts in different applications. Additionally, the results of the cognitive conflicts demonstrate that, at least immediately following the remediation assignment, budget learning gains can be significantly increased by tailoring assignments to specifically challenge areas of student misunderstanding.
References


CHAPTER 4: General conclusions

Discussion

The work reported in this thesis reinforces other findings showing widely held misconceptions of mass balance principles among the general public. As it was demonstrated here, understanding budgets varies significantly by gender and interest in science. Males performed significantly better than females on budget questions and students who were interested in science scored significantly better on budget questions than students who were not interested in science.

Budget understandings in general are poor. This is especially true when budget data are represented graphically to students. Students hold a pattern-matching misconception in which they match inflow rates with overall reservoir levels, which is likely related to students’ poor graphical interpretation abilities. These misunderstandings can be remedied, though not easily. Applying learning theory principles, particularly principles of constructivist learning theory, in the development of a remediation assignment resulted in significant learning gains for students who completed the assignment. These learning gains were enhanced when the students’ identified misconception was specifically targeted by the use of cognitive conflicts.

The pattern-matching misconception discussed in this work appears to be widely held among students and likely extends to most of the general public. Prior knowledge is fervently held, and so conceptual change when this prior knowledge is scientifically inaccurate does not come easily or expediently. It would be presumptuous to assume that a single assignment of one and a half hours in duration would be sufficient to overcome
an idea people have likely held for many years. Given this, the limited yet significant
learning gains observed following the remediation assignment is a testament to the
strength of constructivist learning theory and our general understanding of how people
learn.

Future work in in addressing budget misconceptions should consider the nature of
student misconceptions being so firmly engrained. Even activities which seem sufficient
enough to remedy a misconception may fall far short if they do not target multiple
aspects of students’ misunderstandings. The remediation assignment described here
would benefit from expanding to include cognitive conflicts of not only matching
maximum inflow with maximum stock levels but also matching minimum inflow with
minimum stock levels.

Although computer programs simplify many things, they cannot completely
simplify learning. Learners still need environments that are fashioned after the research
findings of multiple learning theories (Constructivist, Social, Developmental, and
Behavioral). With respect to social learning theory, students need to communicate with
peers, express their ideas with language and have ideas presented to them from someone
who is “at their level” (i.e. within their zone of proximal development). The remediation
assignment presented in this work did not stress the tenets of social learning theory as
well as it should have. In the future, one should insist that the remediation assignment is
completed in small groups, if possible, with additional class or larger group discussions
taking place periodically as a means of providing students with feedback. Feedback is
absolutely essential to student learning and to creating the social environment required to
come to understand difficult, counterintuitive scientific ideas.
The effectiveness of the remediation assignment would also benefit from being tested with a larger sample size, such as an entire lecture class. If the remediation assignment were tested in a large lecture class, the discussions advocated in the preceding paragraph may be more difficult to carry out, though still possible, of course. The discussions in a lecture class would likely have to follow the completion of the assignment, which would have to be assigned as homework if still administered through ThinkSpace and all students are not provided access to a computer in the class.

What is clear is that students’ budget misconceptions must be explicitly challenged in order for cognitive change to occur, and even then students still may not fully relinquish their incorrect ideas. The latter concern is one reason why additional group or class discussions would be necessary to more adequately address budget misconceptions: the discussions would provide yet another experience for students to internalize a scientific understanding of budgets and would provide students with opportunities to voice and hear ideas in more familiar language and within the boundaries of their zone of proximal development. Thus, in general, addressing budget misconceptions more adequately requires a more complete integration of the four learning theories described in the beginning of this work.
Acknowledgements

I am heavily indebted to my advisor, Dr. Cinzia Cervato, for her continued oversight, guidance, feedback, encouragement and kindness. I thank Dr. Cervato and my other committee members, Dr. William Gallus and Dr. Dale Niederhauser, for the formulation and support of this project. Dr. Michael Larsen’s statistical analyses and feedback on manuscripts was indispensible. Dr. Pete Boysen’s assistance with the development and technical support of ThinkSpace was also essential. This work also benefited from the contributions of Katherine Klingseis’s literature searches, Aliye Karabulut’s help in the development of the remediation assignment, John Byers’s feedback and trial runs of the ThinkSpace assignment, and from the students enrolled in Geology 100 and 100L who freely participated in the surveys and experimental assignment. Thank you all.

I would also not be able to do what I do without the support of my wife, Michelle, and my family. I have been fortunate to live in environments that promote intellectual development; environments that are scarce in a society that is frequently hostile to scholarly work. Iowa State University has been a wonderful and safe environment for intellectual work and I am happy to have been a part of it.
Appendix: Survey completed by students.

1. What is your gender?
   A. Male
   B. Female

2. What is your age?
   A. 15-18 years old
   B. 19-21 years old
   C. 22-24 years old
   D. 25-27 years old
   E. 28-30 years old
   F. 31-35 years old
   G. 36-40 years old
   H. Older than 41 years old

3. What is your college?
   A. Liberal Arts & Sciences
   B. Veterinary Medicine
   C. Human Sciences
   D. Business
   E. Engineering
   F. Design
   G. Agriculture & Life Sciences
   H. Graduate

4. What is your current year in college?
   A. Freshman
   B. Sophomore
   C. Junior
   D. Senior
   E. Graduate
   F. Other (high school)

5. What is the highest educational level completed by your mother?
   A. Did not graduate from high school
   B. High school
   C. Some college
   D. Two-year degree program or technical certificate
   E. Bachelor’s Degree
   F. Degree beyond Bachelor’s (Law, Business, Medical, Dental, MS, PhD etc.)

6. What is the highest educational level completed by your father?
   A. Did not graduate from high school
   B. High school
   C. Some college
   D. Two-year degree program or technical certificate
   E. Bachelor’s Degree
   F. Degree beyond Bachelor’s (Law, Business, Medical, Dental, MS, PhD etc.)

7. What is your level of interest in science?
   A. Very interested
   B. Somewhat interested
   C. Neutral
   D. Not very interested
   E. No interest at all

8. How concerned are you about the environment?
   A. Very concerned
   B. Somewhat concerned
   C. Neutral
   D. Not very concerned
   E. Not concerned at all

9. Do you recycle?
A. Usually
B. Sometimes
C. Never

9.2 Do you reduce consumption, e.g. take a bag to the grocery store?
A. Usually
B. Sometimes
C. Never

9.3 Do you conserve water, e.g. turn off faucets when brushing teeth or taking short showers/baths?
A. Usually
B. Sometimes
C. Never

9.4 Do you conserve energy, e.g. turn off unneeded lights, set thermostat to use less energy?
A. Usually
B. Sometimes
C. Never

9.5 Do you reduce transportation energy use, e.g., take public transportation, carpool or ride a bike whenever possible?
A. Usually
B. Sometimes
C. Never

9.6 Do you tell others about conservation and/or environmental issues?
A. Usually
B. Sometimes
C. Never

9.7 Do you learn (read, watch, listen) about environmental issues?
A. Usually
B. Sometimes
C. Never

9.8 Do you use renewable energy (solar, wind) in your house?
A. No
B. Yes

10. Which statement most closely resembles your thoughts on global climate change (global warming)?
A. It is very serious
B. It is somewhat serious
C. It is not very serious
D. Global climate change is not a problem
E. I don’t know

11. What is your understanding on the scientific consensus on global climate change/global warming?
A. Very few scientists think that global climate change will/is occurring
B. Scientists are split about 50/50 on the chances of global climate change occurring
C. The majority of scientists agree that global climate change will occur/is occurring
D. There is still not enough data for scientists to make an informed decision about the chances of global climate change occurring
12. (Q1) Currently, the amount of carbon that human activity inputs into the atmosphere is around 8 billion tons per year. The amount of carbon that is removed from the atmosphere by oceans, trees, and other factors is about 50% of that or 4 billion tons per year. The carbon input into the atmosphere by human activity has been increasing and is predicted to continue increasing. Based on this information, what would the world have to do to decrease the level of carbon in the atmosphere?

A. Stabilize the amount of carbon input into the atmosphere at 12 billion tons per year
B. Stabilize the amount of carbon input into the atmosphere at 8 billion tons per year
C. Decrease the amount of carbon input into the atmosphere to 6 billion tons per year
D. Decrease the amount of carbon input into the atmosphere to 4 billion tons per year
E. Decrease the amount of carbon input into the atmosphere below 4 billion tons per year
F. Natural cycles of the Earth would decrease the carbon level in the atmosphere within our lifetimes without any human action

13A. (Q2) If we steadily decreased our carbon input to the atmosphere starting in the year 2025, reached the removal rate (i.e. the amount of carbon removed from the atmosphere by the Earth) by the year 2075, kept emissions constant until 2099 and then dropped below the removal rate in 2100, in what year would the carbon level in the atmosphere begin to decrease?

A. 2025
B. 2075
C. 2100
D. 2125

13B. (Q3) During which period of time would atmospheric carbon levels be stable?

A. 2025-2075
B. 2075-2099
C. 2100-2125
D. None of the above

13C. (Q4) At what point would the carbon level in the atmosphere first reach its peak (highest level)?

A. 2025
B. 2075
C. 2100
D. 2125
14A. (Q5) In the graph below, the x (horizontal) axis represents time. The y (vertical) axis represents the amount of carbon. The input (blue) line shows the amount of carbon that is added to the atmosphere through human activities, the removal (red) line is the amount of carbon that is removed from the atmosphere by natural processes. At what point would atmospheric carbon levels be highest?

A.  
B.  
C.  
D.  
E.  

14B. (Q6) At what point would atmospheric carbon levels be lowest?

A.  
B.  
C.  
D.  
E.