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Abstract
As technology continues to make information and facts readily accessible, the importance of understanding the context of the information and demonstrating how to use it appropriately will provide better indications of learning than factual recall. This chapter examines the manner in which curriculum and assessment reforms are moving toward promotion of student skill development beyond traditional content knowledge recall. A discussion of the current state of non-content skill assessment in chemistry is presented noting in particular that instructor interest in non-content aspects of learning appears to outpace the measurement of them. Additionally, the chapter presents data from a national survey. These data were used to understand the relative importance of non-content goals and skills in the general chemistry classroom. How these data will inform future efforts to create appropriate formative and summative assessments of goals and skills beyond content knowledge is also discussed.

Disciplines
Curriculum and Instruction | Higher Education | Other Chemistry | Science and Mathematics Education

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The Role of Non-Content Goals in the Assessment of Chemistry Learning

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As technology continues to make information and facts readily accessible, the importance of understanding the context of the information and demonstrating how to use it appropriately will provide better indications of learning than factual recall. This chapter examines the manner in which curriculum and assessment reforms are moving toward promotion of student skill development beyond traditional content knowledge recall. A discussion of the current state of non-content skill assessment in chemistry is presented noting in particular that instructor interest in non-content aspects of learning appears to outpace the measurement of them. Additionally, the chapter presents data from a national survey. These data were used to understand the relative importance of non-content goals and skills in the general chemistry classroom. How these data will inform future efforts to create appropriate formative and summative assessments of goals and skills beyond content knowledge is also discussed.

Introduction

In a world where facts are accessible with a click of a button, simple factual recall is no longer the appropriate principle indicator of learning. Rather the context of the knowledge and the ability to use it appropriately are of greater importance. Official reports that use this premise to call for various education
reforms have been prominent components of policy debates (1). Not surprisingly, calls for curriculum reform in chemistry often echo these sentiments. One theme for implementation of suggestions such as these notes the need for data-driven and evidence-based curriculum and assessments (2–5).

Beyond the policy calls, and at least partly in response to them, several efforts to revise science curricula have arisen. Among the most ambitious are the recent changes in both the curriculum and tests associated with Advanced Placement (AP)® courses in several sciences, including chemistry (6). In this case, developers at College Board have shifted to an evidence-based approach to curriculum design that utilizes Evidence Centered Design (ECD) (7) along with principles of “backwards design” (8, 9). In this model for curriculum design, learners are expected to master not only content essential to the understanding of scientific concepts, but additionally meet expectations about what they should be able to do with that knowledge (10). In order for ECD to accomplish its goals, assessments need to be carefully constructed in order to measure whether a learner has successfully achieved all of the desired outcomes for the course beyond recall of factual knowledge. The current state of this curriculum development process is described in the re-designed AP chemistry curriculum by College Board (11).

A key component of this approach lies in the definition of learning objectives (LOs) that were specifically created to integrate “essential knowledge” (content) and “science practices.”

The Next Generation Science Standards (NGSS) are designed in similar fashion to the reforms of AP courses at the high school level. The ultimate goal of the NGSS is to aid science education at the K-12 level by describing what all students should know and be able to do by certain grade levels (12). While there is no standardized curriculum or assessment associated with the NGSS, the interconnectedness of core content, practices, and crosscutting concepts implies that assessments will need to measure all three cohesively.

Regardless of the intended audience of the reform effort, it is evident that attempts to move beyond simple factual recall assessments to develop rich assessments that measure the development of student skills and practices are becoming increasingly commonplace. The effects of such efforts promise to change how chemistry is taught and assessed at the post-secondary level, as future generations of college students may enter the classroom prepared to engage with the content in different ways. With this potential future in mind, the goals of general chemistry instruction and assessment at the collegiate level should be prepared to consider the development of content knowledge and to encompass development of skills and practices that students can transfer to other courses and disciplines.

What such a curriculum and assessment regime might look like in practice is not yet established in the literature. The concept of considering curriculum development in conjunction with assessment reform has been proposed (13) where assessment design is driven by curriculum prerogatives, and assessment data informs changes in curriculum. This is not to say that multiple modes of assessment have not already been developed within chemistry. Nonetheless, evidence suggests that many chemistry faculty members are aware of a relatively small number of assessment methods and instruments (14–16).
Currently, efforts within the chemistry education research community are seeking to provide means for assessment of student performance beyond content. Assessment instruments used in chemistry education include several that are not directed strictly at content knowledge measurement. For example, an instrument to measure student attitudes about learning chemistry, Attitude toward the Subject of Chemistry Inventory (ASCI), was created by Bauer (17). The instrument measures students’ attitudes by asking students to select the position on a semantic differential that most closely relates to their perceptions of chemistry. Xu and Lewis later refined the instrument to a shorter version which measures fewer constructs than the original (18). Other instruments such as CHEMX (19) and CLASS (20) focus on students’ expectations and beliefs about chemistry. The CHEMX instrument aims to compare student expectations of the chemistry learning environment to those of faculty within the context of a specific chemistry course, including the laboratory. The CLASS instrument compares student beliefs about chemistry in general to those of experts. While some of the constructs measured by the two instruments overlap, each instrument measures a unique piece of the chemistry experience from the perspective of students. Additionally, the Metacognitive Activities Inventory (MCAI) measures students’ metacognitive awareness and how that awareness influences chemistry problem solving skillfulness (21, 22). It is important to note that this summary highlights only a small fraction of the number of published instruments available for use in chemistry instruction. While these assessment instruments do not specifically intertwine the measurement of chemistry content knowledge with content independent skills, they are important for use in classroom contexts to understand better the development of specific attitudes and skills by students.

The number and variety of assessment instruments that have been developed illustrates the apparent demand for assessment measures that go beyond content knowledge. To some degree, however, instrument development has tended to result in only modest implementation. In other words, the number of times in which non-content aspects of learning have been explored in a preliminary way via instrument development is growing, but day-to-day usage of such tools has shown a less robust pattern, at least in terms of literature (23). This does not imply an outright lack of interest in the measurement of non-content learning goals. Indeed, usage of assessment tools in classrooms that go unreported in the literature may be common. Nonetheless, from the literature base alone, it is not easy to ascertain the key non-content characteristics chemistry instructors feel are important to measure. Therefore, it is important to 1) understand what skills and practices general chemistry instructors value for students to develop and 2) think about how future assessment designs might incorporate essential content with skill assessment.

Arguing the Importance of Non-Content Assessment in Chemistry

Beyond the impetus from emerging curriculum development and studies within chemistry education research, there are two important aspects of chemistry instruction that suggest the measurement of non-content goals may be important. First, theories of how people learn have repeatedly included key components
that are not formally related to content knowledge alone. Second, for many forms of pedagogical improvement, an increase in non-content components of learning may be important. In this sense, the potential importance of measuring non-content goals follows a familiar theory and practice breakdown that can be elaborated further.

Theories of Learning and the Role of Non-Content Assessment

Novak’s Theory of Education, Human Constructivism, is integral to the design and analysis of this research (24, 25). Novak draws heavily upon the ideas of psychologist and philosopher David Ausubel’s assimilation theory which describes the differences between rote and meaningful learning, outlines the conditions necessary for meaningful learning, and suggests that meaningful learning occurs when the learner is afforded experiences in each of the three learning domains (cognitive, affective, and psychomotor) (26). Meaningful learning is achieved only when all three components are present.

Novak’s theory asserts that knowledge is a human construction, and thus it is incumbent upon the educational system to support learners as they construct knowledge (24). Additionally, meaningful learning empowers students to commit and be responsible for learning by integrating thinking, feeling, and acting. Therefore, this framework provides a unique lens to analyze the learning goals of general chemistry instructors because it establishes a basis to understand how the learning goals provide an opportunity for meaningful learning in a general chemistry course (27).

It is also important to consider that the general chemistry classroom provides experiences that are unique to the discipline of chemistry. That is to say that the learning that occurs within the general chemistry classroom is situated within the context of a chemistry community. Thus it is useful to consider that activity, concept, and culture found within the chemistry classroom are interdependent. The theory of situated cognition provides an additional lens for understanding the role of activity to develop skill and concept creation within the realm, or culture, of general chemistry (28). It is posited that even though students acquire tools, or skills, they will not know how to use them appropriately if not given opportunities to use them within the context of the discipline (28). This suggests that even though opportunities for meaningful learning may be presented to students, the knowledge and skills acquired may remain decontextualized, and even inert, unless students are presented with insight about how those concepts and skills are actually used within chemistry and how to transfer them to applicable real-life situations (29).

Additionally, the importance of the interconnection of content knowledge and procedural skills in understanding learning is shown within the Unified Learning Model (ULM) (30). The ULM provides a model of how people learn, and a resultant model of teaching and instruction, by drawing on the principles of cognitive science and psychology. In this model, working memory, knowledge, and motivation are central to understanding how all people learn. Knowledge in this case refers not only to concepts or facts (declarative knowledge), but also to
the skills, behaviors, and thinking processes that an individual knows (procedural knowledge). Learning is then influenced by the individual’s working memory capacity, the concepts and skills he or she already knows (prior knowledge), and the goals that drive him or her to put forth effort. In this model the instructor aids the learner by directing the student’s attention (working memory) to the concept or skill to be learned, providing opportunities for the creation of new connections between prior knowledge and the new concept or skill, and creating goals to support the motivation of the student to learn. In this sense the instructor serves as a mere facilitator of individual learning, yet guides the course of the learning experience by influencing the content and skills developed through specific course goals and objectives.

Practical Implications of Measuring Non-Content Learning in the Classroom

There is little question that content knowledge gains represent the main goal of any course, and chemistry courses are no exception. However, it is also true that understanding just how teaching methods influence the efficiency of learning often hinges on non-content aspects. In particular, the concepts of student engagement, student motivation or student persistence have received considerable attention in research studies regarding how to promote learning success in chemistry (31–33). Perhaps just as importantly, the measurement of non-content variables is often measured as a part of formative assessment during attempts at curriculum or pedagogical innovation. Determining whether or not students “like” a new approach, is often reported – but it is arguable that non-content learning can be parsed with significantly more resolution than this construct.

Several teaching methodologies have emerged with an intention to improve content learning and provide non-content gains as well. Within chemistry, Process Oriented Guided Inquiry Learning (POGIL) is perhaps the most prominent example (34–37). For this teaching method, the process-orientation component is focused on enhancing the development of generalizable process skills that allow students to gain more content knowledge. Other teaching methods such as problem based learning (38), case-based historical development of chemical concepts (39) and active learning via a “flipped” classroom (40) all include aspects that relate to student engagement and non-content skill development.

While a number of research questions related to the assessment of the non-content components of these emerging methodologies still remain, the methodologies themselves serve to exemplify the practical nature of enhancing student skills in addition to content knowledge.

Before researchers can address creation of assessment materials for measurement of non-content goals and skills, it is necessary to understand what are the goals and skills that chemistry instructors value. The survey and data presented here aim to inform the community about the types of goals and skills that are valued in the general chemistry curriculum.
Methodology for the Study

Survey Development

Quantitative survey items were developed from themes present in qualitative interviews conducted with chemistry instructors about the learning goals present in introductory general chemistry courses. The semi-structured interviews were conducted with 18 general chemistry instructors from high schools, community colleges, and state-funded universities. Participants were asked open-ended questions that progressively became more specific depending on a participant’s response, such as “What are the learning goals you have for your general chemistry course?” to “What are the non-content goals you have for students in your course?” (41). The interviews were then transcribed and open-coded using a Grounded Theory approach (42). Additionally, learning goals were labeled according to the primary domain (cognitive, affective, or psychomotor) associated with the goal. Interestingly, participants often discussed incorporating a variety of goals into their courses, but felt that students did not meet the often implicit expectations associated with these goals even though they did not formally assess their non-content goals (41). In order to obtain more generalizable results about the status of non-content learning goals, the ten most frequently discussed non-content goals from the interviews were transformed into survey items. The survey items were part of a national online survey from the ACS Examinations Institute about conceptual understanding in general chemistry.

The major non-content goals surveyed were: appreciation of chemistry in everyday life, development of communication skills, laboratory skills, graphing of data, interpreting and drawing conclusions from data, life skills (e.g., study skills, responsibility, time management), problem solving skills, nature of science (i.e., how science works and has developed), critical thinking, and conceptual understanding of traditionally algorithmic problems.

Survey Items

Three questions on the survey related to non-content goals and each question evaluated all ten non-content skills identified as common themes amongst qualitative interview participants.

The first question related to learning goals asked participants to indicate how often they intentionally and explicitly incorporated the learning objectives into their course. Response choices ranged from “I do not incorporate this” to “Every class period,” with options of “Once or twice per semester,” “Once per month,” and “Once per week” in between. Participants were only able to select one response choice per learning goal.

The second question in the set related to how the learning goals were assessed in the course. Participants were asked to select all modes of assessment that applied to each learning goal. Methods of assessment surveyed were clickers (student response systems), exams, homework, laboratory reports, and quizzes.
Additionally, response options were available for participants that did not assess or did not incorporate a goal in the course.

The final question related to learning goals asked participants to describe, on average, how well they felt that students met their expectations for these learning goals. Respondents were allowed to choose one response from five choices ranging from “Below my expectations” to “Exceeds my expectations.”

Sample

The sample consisted of chemistry instructors and faculty at community colleges, four-year colleges, and universities in the United States who had taught a general chemistry course within the past five years. Institutional classifications were based upon the self-reported highest degree offered in chemistry at the participant’s institution. The sample excluded instructors of special topics courses and General, Organic, and Biochemistry (GOB) courses. For analysis purposes, only participants who completed all questions relating to learning goals were considered as part of the sample (N=1,075). Table 1 shows participant distribution by institution type. General chemistry teaching experience of participants ranged from one year to 40 years experience, with an average of approximately 15 years. Additionally, 84% of the sample had taught a full-year (two-semester) general chemistry course and 75% were responsible for teaching both a lecture and laboratory component of the course.

Table 1. A Description of Quantitative Survey Participants by Institution Type

<table>
<thead>
<tr>
<th>Institution Type</th>
<th>Participants</th>
<th>Percent of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community College</td>
<td>170</td>
<td>15.8</td>
</tr>
<tr>
<td>Bachelors Institution</td>
<td>513</td>
<td>47.7</td>
</tr>
<tr>
<td>Graduate Institution</td>
<td>392</td>
<td>36.5</td>
</tr>
<tr>
<td>Total</td>
<td>1,075</td>
<td>100</td>
</tr>
</tbody>
</table>

Results

Quantitative Survey Results and Discussion

Results from the survey provided insight into chemistry instructors’ values of non-content goals and skills.

Responses to the first question about frequency of intentional incorporation of non-content learning goals were as expected. Skills traditionally associated with chemistry courses, such as conceptual understanding, critical thinking, and
problem solving, were reported to be incorporated into every class period by a majority of instructors. Figure 1 displays the frequency of incorporation of the non-content goals and skills as self-reported by instructors. Problem solving appeared to have the highest frequency of incorporation. Approximately 74% of instructors reported incorporating problem solving into every class period, and an additional 22% reported incorporating it on a weekly basis. Less than 1% (0.28%) of instructors reported not incorporating development of problem solving skills as a goal of their general chemistry course. Critical thinking and conceptual understanding also had a majority of respondents indicate that they incorporate those skills into every class period with 58% and 56%, respectively. Additionally, nearly 70% of instructors reported incorporating laboratory skills on a weekly basis. This is consistent with the typical general chemistry course design, which includes a weekly laboratory section. Other goals, such as development of communication skills, showed a broader range of reported incorporation.

Figure 1. General chemistry instructors’ self-reported incorporation of non-content goals and skills. Incorporation ranges from every class meeting to not incorporated at all.
While these statistics are not surprising due to the nature of general chemistry coursework, it is important to note that these data are self-report so we cannot ascertain for certain whether instructors are actually incorporating these goals in the manner in which they claim. For example, while over 95% of instructors claim to incorporate problem solving into their course at minimum on a weekly basis, it is unclear as to whether participants in this survey were differentiating the nature of problem solving, such as how the course activities might be compared with students performing learning exercises (43). Such distinctions are not wholly necessary for this study because these data were not meant to assert sweeping observations about the condition of the collegiate general chemistry classroom. Rather, the objective is to understand the types of goals and skills that are valued by general chemistry instructors in an effort to understand better the types of non-content skills that future formative and summative assessments could be designed to measure. In this context, it is considered that an instructor who makes an effort to incorporate a goal or skill more frequently likely values that skill more and desires to develop it in students more so than goals that are incorporated on a less frequent basis.

The frequency with which instructors reportedly incorporate non-content goals and skills into their courses provides an indication of the types of skills they hope to develop in their students. Yet, incorporation of a goal into a curriculum does not imply that students successfully develop that skill. Assessment plays a key role in understanding and rating student skill development. In order to understand better how future assessments might be designed to measure content independent learning goals, it was important to elicit how instructors assess non-content goals within their general chemistry courses. Again, these are self-reported data intended for use to understand how instructors perceive these learning goals to be assessed. Respondents were allowed to select multiple modes of assessment for a single learning goal. The modes of assessment were selected from the most frequent responses collected in qualitative interviews, and included clickers, exams, homework, lab reports, and quizzes. Respondents were also allowed to indicate that a particular learning goal was not assessed in their course.

Instructors’ responses regarding modes of assessment used can be seen in Figure 2.

For ease of interpretation, responses have been combined to reflect summative assessments (exams and quizzes), formative assessments (homework and clickers), laboratory reports, and responses indicating a goal was not assessed. It is of interest to note that laboratory reports were the most frequent response for assessment of communication skills, laboratory skills, graphing of data, and drawing conclusions from data, whereas problem solving skills, critical thinking about concepts or problems, and conceptual understanding of problems traditionally solved algorithmically are reported as most commonly assessed by exams and quizzes.

Other methods of assessment were not selected as frequently. For example, clickers make up a smaller fraction of the formative assessment category compared to homework. Clickers had minimal use in assessment of the non-content goals except for problem solving. This result may not be surprising in light of previous research about clicker usage among chemistry instructors (44). Goals related to
development of an appreciation of the subject of chemistry, understanding of the nature of science (NOS), and life skills were reported as most frequently not assessed in any fashion.

![Figure 2. Instructors’ self-reported methods of assessment of content independent goals and skills in general chemistry courses.](image)

Instructors reported use of assessments gives insight into how opportunities for meaningful learning are being evaluated in the classroom. Skills that lie predominantly in the cognitive domain (problem solving, conceptual understanding, and critical thinking) are reported as most frequently assessed by exams, whereas skills that lie predominantly within the psychomotor domain, with some overlap of the cognitive domain, such as laboratory skills, communication skills, and graphing are measured by laboratory reports. Affective goals such as appreciation of chemistry and life skills are reported as not assessed at all. While
it is not surprising that there is a disconnect between the methods of assessment (or lack thereof) for each domain, it is indicative of the challenge faced by assessment designers to incorporate more than one domain within a single format of assessment.

Regardless of how the learning goals are purportedly assessed, there appears to be room for improvement in student performance. Instructors were asked to evaluate how students met expectations regarding successful development of these learning goals, and their responses can be seen in Figure 3. Although the percentage of students meeting the expectations of their instructors for development of these non-content goals was generally over half, a sizable fraction of students appear to have fallen short in the estimation of the participants in this survey. Indeed, more instructors rated student performance as “Does not meet expectations” than “Exceeds expectations,” suggesting that there is room for improvement in student performance in non-content aspects of learning. It is important to remember, however, that assessment methods that instructors have indicated are used for non-content goals tend to be more informal. As such, the impressions they form (which presumably inform their answers to this survey item) may lack quantitative rigor. Thus, the expectations reported here, while informative about future challenges related to assessment of non-content learning, should not be considered a rigorous judgement of student non-content learning.

Figure 3. Instructors’ evaluation of student performance on achievement of non-content learning goals.
Summary and Implications

Although it may not be routinely articulated by chemistry instructors, the development of skills beyond the scope of content knowledge in chemistry courses is important and most instructors view it as such. Curriculum reform efforts often influence non-content learning outcomes but without a more rigorous effort to enhance assessment it may be argued that these changes essentially resort to a “hope for the best” approach. The survey research presented here provides evidence that non-content learning goals are valued by the chemistry education community. As such, assessments are needed to measure the development of students’ skills beyond typical content exams.

Calls for changes in the chemistry curriculum focus on the need for evidence-centered and data-driven reform efforts (2–5), beyond measuring whether students “like” an activity. Instruments have been developed to measure student skills beyond the domain of chemistry content knowledge; however, these instruments appear to be underutilized by the traditional chemistry community, perhaps due to a lack of awareness of these instruments. Additionally, these instruments tend to be quite specific and measure only specified constructs. This means that to gain a whole picture of the classroom environment, an instructor would likely need to devote significant effort to administering and analyzing survey instruments. This level of effort may not be practical in the typical general chemistry classroom.

Ultimately, the most attractive trajectory for addressing the need for non-content assessment may lie in finding ways to incorporate it more closely within traditional content assessments. Efforts to devise such assessment are part of the high profile developments in AP Chemistry (6–11) and the Next Generations Science Standards project (12). In order to guide such development the current work suggests an iterative process may be particularly helpful to determine what non-content skills are most important to assess in this way. Instructors appear to be interested in gaining better information about student learning, but it seems reasonable to expect that initial attempts to measure non-content aspects may require refinement. Thus, the collaboration between curriculum reform efforts and assessment development efforts (13) will take on ever more importance as chemistry education moves forward over the next few years.

References