AC 2008-116: GUIDED INQUIRY LESSONS FOR INTRODUCTION TO MATERIALS

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Abstract

This proposal describes a project to develop and test new classroom materials for the Introduction to Materials course within the engineering curriculum that utilize an active learning, team-based approach. This pedagogy has been termed Process Oriented Guided Inquiry Learning (POGIL), and is based upon the learning cycle model. Rather than sitting in traditional lectures, students work in teams to complete worksheets that guide them through the process of learning. In this way students are actively engaged in processing the information and have the opportunity to utilize and develop important skills such as teamwork, communication, and critical thinking. Assessment of the effectiveness of this approach is being conducted using measures of content knowledge through the Materials Concept Inventory and student self-assessment of their learning through the Student Assessment of Learning Gains. Preliminary analysis of data from the MCI for a portion of the control group shows that there are significant gains in learning even in a traditional lecture class, and that the MCI appears to have some bias against women.

Introduction

Traditional models of teaching are focused on the delivery of content. It is assumed that learning occurs by the instructor telling the students the information. The problem with this approach is that it does not match with the research on learning. The well-known cognitive model of learning, developed in the field of psychology, describes the processes by which a learner acquires new information.[1] Figure 1 illustrates this model. The key point to note in this model is that information is actively manipulated in the mind of the learner within the context of the existing structure of the learner's long-term memory. The learner has essentially three options: 1) The information can be accommodated into the existing structure. The traditional lecture approach assumes that this always occurs; 2) The new information does not fit into the existing

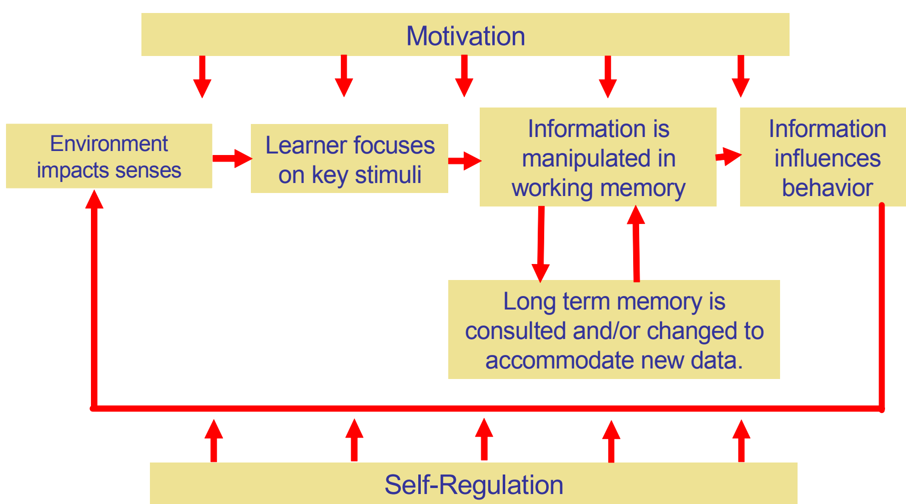


Figure 1: Schematic diagram illustrating the cognitive model

structure, and a state of disequilibrium occurs. At this point the structure of long-term memory needs to be changed to accommodate the new information, or 3) The new information is rejected and long-term memory is left unchanged. As an example, Lawson describes the process by which Darwin developed the theory of evolution.[2] Observations during his voyage to the Galapagos conflicted with his view of a Creator, leaving him in a state of disequilibrium. In order to resolve this conflict, he developed the theory of evolution.

In the classroom, such a process of information processing underlies the constructivist approach to learning. The constructivist approach states that learning occurs when learners "…think about what the teacher tells them and interpret it in terms of their own experiences, beliefs, and knowledge."[3] One practical application of how to apply the constructivist approach is through the learning cycle model.[2,4,5] (Note that this learning cycle model is different from Kolb's learning cycle,[6,7] although there are some similarities.) In this model there are three phases of learning. The first is the exploration phase, in which the learner manipulates data or information. This results in the second phase, which is concept invention or term introduction. In this phase the learner uses the data to develop general rules or concepts. Finally is the application phase, in which the learner applies the concepts developed to new situations. This learning cycle models both the scientific research process, and the way young children learn about their world. In traditional teaching, the exploration phase is skipped, and teaching begins with concept invention. In contrast, studies have shown that learning occurs better when the concept invention phase comes later in the sequence.[4,8,9] This approach is most powerful when the learners themselves invent the concepts (rather than having it told to them). This approach is the basis for constructivist teaching. In a constructivist approach the roles of the instructor and students are quite different from a traditional class. Table 1, taken from Spencer,[10] compares those roles for the two approaches.

The use of a constructivist model of learning has been recognized as providing significant benefits for learning, and a number of different ways of creating a constructivist, or learner-centered, classroom have been described.[11] In this paper one particular approach, called process-oriented guided inquiry learning, is described.

Process Oriented Guided Inquiry Learning

In a guided inquiry class, the instructor does not lecture. Rather students work in teams, typically of four students, to complete worksheets. The worksheets contain three components: 1) Data or information as background material; 2) Critical thinking questions, which are designed to lead the students to understanding the fundamental concepts represented by the data, and 3) Application exercises, which provide the students with practice in solving problems using the concepts they have derived. The instructor's role is to guide the students, walking around the room and probing them with questions to check their understanding.[12,13] Farrell et al. have described the roles of students within the groups and the class procedures.[12] Typical roles are Manager (responsible for ensuring that tasks are completed), Recorder (records the groups answers), Presenter (presents group answers to the class), and Reflector (observes and comments on group dynamics). The typical class period proceeds as follows:

Table 1: Comparison of instructor and student roles in traditional and constructivist models.[10]

Role of Instructor		Role of Student	
Traditional	Student Focused	Traditional	Student Focused
Lectures	Acts as consultant	Asks for the "right" answer.	Explains possible solutions or answers and tries to offer the "right" explanations. Tries alternate explanations and draws reasonable conclusions from evidence. Has a margin for related questions that would encourage future investigations.
Explains concepts	Asks probing questions of students to derive concepts.	Has little interaction with others.	Has a lot of interaction and discusses alternatives with others. Checks for understanding from peers.
Provides definitive answers.	Elicits responses that uncover what the students know or think about the concept.	Accepts explanation without justification.	Is encouraged to ask questions such as, Why did this happen? What do I already know about this? Is encouraged to explain other students' explanations.
Tells the students they are wrong or right.	Provides time for students to puzzle through problems.	Reproduces explanation given by the teacher/book.	Tests predictions and hypotheses. Uses previous information to ask questions, propose solutions, make decisions, and design experiments.
Explains to students step-by-step how to work out a problem.	Allows students to assess their own learning and promotes open-ended discussion. Refers students to the data and evidence and helps them look at trends and alternatives. Encourages students to explain other students' concepts and definitions in their own words.		

1. Instructor posts team assignments and roles for that day. Teams will typically stay intact for several class periods, although roles will change each day.
2. The instructor distributes information, such as the recorder's notes from the previous day with comments from the instructor.
3. A brief recap of the previous day or an introduction to that day is given by the instructor.
4. Students begin working on the day's activities.
5. The instructor observes the groups and may interact with them in several ways. He may respond to questions from a particular group, or may ask questions of particular members of a group. This latter technique is particularly useful if it appears that one member of a group is lagging behind the other members in understanding, or if it appears that one member is dominating the discussion in a group.
6. If a particular question is causing difficulty for several groups, the instructor may choose to interrupt all groups, and have the presenters from each group discuss their group's answer. In this way, different approaches can be compared and a consensus answer obtained.
7. With about 5 minutes left in class the instructor stops the activity. He may summarize the day's activities himself, or ask the presenters to present some aspect of their group's work as a means of providing a summary.
8. Students are then given a brief period of time to answer a series of questions, such as: What was the most important thing you learned today? What question do you still have about the material? What was a strength of your group's performance? What could be improved about your group's performance? The answers to these questions serve as the basis for the review and introduction for the next day.
9. The recorders turn in the answer sheets for their group. Any problems not completed can be assigned as homework.

A number of practical issues need to be considered when implementing guided inquiry activities. From a pedagogical standpoint the goal is to assist the students to be responsible for their own learning. In this sense, there are no inherent limitations on the use of this approach at any level of materials science and engineering courses. As with any approach to teaching, considerations of course content need to be considered in conjunction with the effectiveness of student learning. It is the author's personal opinion that improved student learning takes precedence over covering a certain amount of material (assuming that content which is prerequisite for another course is covered), but the relative benefits of content coverage versus improved student learning has not been investigated empirically for guided inquiry classes. Some of the questions that would need to be investigated are whether or not there actually is a loss of content when guided inquiry is used, and if there is what the impact on follow-on courses would be.

Another important issue is the number of students in the class. Guided inquiry classes can be utilized with any class size. However, when it is implemented in large (greater than 40 students) classes additional aspects need to be considered. Because the instructor can not effectively monitor the progress of every group, it is beneficial to break the worksheet into smaller sets of questions and review the answers with the entire class throughout the period, rather than simply letting the groups work continuously throughout the class period. The choice of reviewing the answers with students in this way is a compromise between giving the students ownership of learning and ensuring that all students are on track.

As guided inquiry has not yet been implemented in engineering, how these issues impact implementation in engineering in general, and materials science and engineering in particular, has not been resolved. However, based on experience in chemistry they are not expected to be major obstacles to implementation. Within chemistry, guided inquiry has been used both for introductory courses (general chemistry and organic chemistry) as well as more advanced courses (thermodynamics and quantum mechanics). In addition, it has been used for small sections of general chemistry in a liberal arts college and large sections of organic chemistry at a comprehensive university. Thus it is anticipated that there will be no particular issues associated with implementation at any level of materials science and engineering.

Guided Inquiry Worksheets

Guided inquiry worksheets are currently being developed for Introduction to Materials. The Introduction to Materials class is a 3000 level course taken primarily by juniors, but also by sophomores and seniors. It assumes a knowledge of basic science and engineering courses (chemistry, physics, calculus, and statics). For Materials Science and Engineering students it serves as the first course taken within the major, and provides the foundation for later courses in the curriculum. It is also taken by students in other engineering majors as an engineering elective, and is their only exposure to materials science and engineering. The course covers a broad range of material; as taught by the author the topics can be broken down into the categories of materials structure and defects, diffusion, phase diagrams, phase transformations, mechanical properties, composites, corrosion, and electrical properties.

In this project, activities are being developed that cover the topics currently taught by the author in his Introduction to Materials class. Specifically, lecture materials for each lesson are being converted into a guided inquiry activity, with each guided inquiry worksheet corresponding to one lecture. The activities are designed to fit into the standard 50 minute lecture period, although they could be written for longer period classes if that is needed. Each activity consists of the following components:

Information: This may be a graph, table, demonstration, or reference to information in the text.

Critical Thinking Questions: These questions guide the students to an understanding of the concepts in that particular activity. Each activity contains three types of questions. *Directed questions* focus the students' attention on specific aspects of the data, and the answer is found directly in the Information. (E.g. What is the composition of the metallic alloy shown in the Information?). *Convergent questions* help the students to bring together the data to come to a general conclusion or understanding of the concepts. The answer is not directly available from the Information and requires analysis and synthesis. (E.g. Based on your answers to questions 1-5, how does the strength of a single phase alloy change as the composition changes?) *Divergent questions* are open-ended questions that ask the students to expand on their new knowledge by pondering, further exploring, and generalizing. (E.g. Which is more effective at strengthening aluminum, solid solution strengthening or precipitation hardening? Justify your answer on the basis of technical and/or economic considerations.)

Exercises: These are straightforward homework problems that ask the students to apply the specific concepts they have learned in ways similar to what was developed in the Critical Thinking Questions. (E.g. For each of the following alloys, identify which is the strongest, and explain why.)

Problems: These are higher order thinking homework problems that ask the students to apply the concepts in new and unfamiliar contexts. Often these will be "real world" problems. (E.g. Using data from your text, determine if it is possible to create a Cu-Ni alloy with a minimum strength of 300 MPa and a minimum ductility of 40%. If it is possible, identify the composition of the alloy. If it is not possible, explain why.)

A specific example of a worksheet for the Introduction to Materials class is provided in the next section. This worksheet addresses a specific conceptual problem encountered by the author when teaching this course, namely an understanding of the physical meanings of phase compositions and phase amounts in materials. The worksheet shown in this proposal is the instructor version, which includes a brief discussion of the overall concept underlying the worksheet, and identification of each question as being directed, convergent, or divergent. These items would be removed in the version provided to the students.

This particular worksheet would appear approximately halfway through the semester. At this point the students have been exposed to the structure of materials, and the effect of structure on properties (e.g. solid solution strengthening, precipitation hardening, etc.). In the class period immediately prior to this one they have learned the definitions for terms associated with phase diagrams: component, phase, solubility limit, microstructure, morphology, etc. Thus, Critical Thinking Questions 1-4 are directed in the sense that the students use the definitions from the previous period and the information provided to them to answer the questions directly, reinforcing the previously learned material. In questions 5-8 they must synthesize the concepts they have just learned (definitions of phase composition and phase amount) with concepts from another lesson (how strength changes with composition and phase amount) to provide answers, and there are specific correct answers; thus these questions are convergent. Finally, question 9 asks them to go beyond information directly available to them, and speculate on a possible method. The open-ended nature of the question and the lack of a single correct answer makes this a divergent question.

Example Worksheet

Mixtures 2, Instructor Version

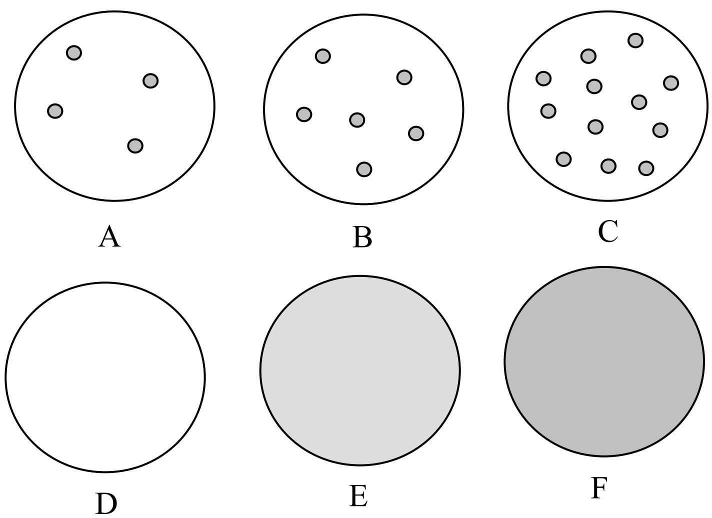
Concepts

Many students can use the lever rule algorithmically to determine phase compositions and phase amounts from phase diagrams, but do not understand what these numbers mean. This activity is intended to help them understand these numbers without the use of phase diagrams. In this context, critical thinking question 9 is particularly important. What is less important for this question is the technique they choose. More importantly is that the technique they choose demonstrates an understanding of the distinction between phase composition and phase amount.

<u>Objectives</u>

1. Differentiate between total composition of a mixture, composition of the phases in a mixture, and the relative amounts of phases in a mixture.
2. Predict how a change in phase composition or phase amount affects the strength of a metallic alloy.

<u>Information</u>



In these pictures, pure aluminum is white and pure copper is black. A darker shade of gray indicates there is more copper mixed with the aluminum.

You are employed by Materials, Inc., a company that develops high strength alloys for the aerospace industry. Your team has been assembled to recommend two aluminum alloys for further development out of several being considered. The pictures shown above illustrate the microstructure of the different alloys that you must choose from.

<u>Critical Thinking Questions</u>

1. How many phases and components are present in alloy A? (Directed)
2. How many phases and components are present in alloy E? (Directed)
3. How do the phase compositions and the amounts of the phases present change from A to B to C? (Directed)
4. How do the phase compositions and the amounts of the phases present change from D to E to F? (Directed)
5. How does the strength of the alloys change from A to B to C? (Convergent)
6. How does the strength of the alloys change from D to E to F? (Convergent)
7. Provide a recommendation as to which alloy your company should pursue, A, B, or C. Explain why. (Convergent)
8. Provide a recommendation as to which alloy your company should pursue, D, E, or F. Explain why. (Convergent)
9. Propose methods to determine the phase compositions and phase amounts in metallic alloys. (Divergent)

Resources available to you are information from the lesson on Strengthening Mechanisms and Callister, Materials Science and Engineering: An Introduction, 6th Edition, p. 174-177, 247-250.

Exercises

1. Draw pictures similar to Model 1 that illustrate the structure of the following alloys:
   a. 25% pure iron and 75% pure copper
   b. 25% α and 75% β, α is 20% iron, β is 60% iron
   c. 25% α and 75% β, α is pure iron and β is 60% iron

Problems

1. Discuss, using grammatically correct English, why it would be important to know phase compositions and amounts of phases present in a material.

Assessment Methods

Summative assessment is being conducted to rate the effectiveness of the worksheets in the classroom. There are three primary research questions for the study:

1. Do students who are in a guided inquiry class have a better understanding of materials concepts than students in a traditional lecture class?
2. Do students who are in a guided inquiry class **feel** like they have a better understanding of materials concepts than students in a traditional lecture class?
3. Is there a differential impact of guided inquiry learning based on sex or ethnicity?

The first question is obviously of importance for understanding whether the guided inquiry approach is effective in a traditional sense. The second question is important from a retention and motivational standpoint. Regardless of the actual improvement in understanding, students who believe that they understand the material are more likely to have feelings of confidence, be motivated to work hard, and to ultimately remain in their engineering program. This last point may be especially important for underrepresented groups.

The question of student understanding will be measured using the Materials Concept Inventory (MCI) developed by Krause et al.[14,15] This is a 30 item multiple choice instrument designed to assess students' level of conceptual knowledge in an introductory materials science class. The validity of this instrument has been established through its construction, which was done by expert evaluation of topics and writing of questions, use of student open-ended quizzes to develop distracters, and use of student focus groups to further refine ambiguous questions and answers. Initial results by the developers of this instrument using a pre-test/post-test design show gains of 15-20% for a standard lecture course versus 38% for a course that included active learning activities.[14] These results indicate that the MCI can sufficiently discriminate between different types of pedagogy.

In order to assess students' beliefs about their learning, the instrument to be used will be the Student Assessment of Learning Gains (SALG),[16] an online instrument designed to focus student assessment on how the pedagogy of the class affected their learning gains, as opposed to issues

Table 2: Correlations between MCI scores and demographic variables. Pearson's correlation coefficient is used when both variables are parametric. Spearman's rho is used when at least one variable is non-parametric. Empty cells in the table indicate that the correlation was non-significant (one-tailed, p>.05).

	GPA	SAT verbal	SAT quantitative	Course grade
MCI pre-test	------	.43*	.35*	.17†
MCI post-test	.33*	.37*	.39*	.37†

*Pearson's correlation coefficient.
†Spearman's rho.

Table 3: MCI results by sex. Numbers in parentheses are number of students (N) followed by the standard deviations. The values of N reflect those students for whom data was available. MCI gain may not equal the difference between the pre-test and post-test scores due to round-off error.

	MCI pre-test*	MCI post-test*	MCI gain
Male	11.9 (87, 3.6)	15.7 (89, 4.0)	3.8 (82, 3.4)
Female	10.3 (25, 2.7)	13.8 (25, 3.7)	3.6 (24, 3.0)

* Significant at p<.05 using a 2-tailed t-test.

of teacher performance or the extent to which students "liked" the class. The validity of this instrument has been established by comparison of the SALG instrument to written comments taken from both the SALG and other instruments.[17]

The guided inquiry approach has not yet been fully implemented, and thus assessment data comparing standard lecture format with guided inquiry format are not yet available. In order to provide some insight into the effectiveness of the standard lecture approach, and particularly how it differentially impacts women, data are presented here for one section of the control group only. Specific comparisons between control (lecture format) and treatment (guided inquiry) groups will be presented in a future publication.

Preliminary results from the MCI for one section of the control group, taught by the author using a standard lecture approach, are shown in Tables 2 and 3. Results show positive correlations between the MCI post-test and the grade obtained by the students in the course, and a significant increase in score from the pre-test to the post-test. It is assumed that this increase over the course of the semester is due to the students participating in the course, although it is possible, but not likely, that other factors may have contributed to that gain. Results on differences by sex show that women consistently score lower, despite there being no difference in general academic ability or grade in the course between men and women.[18] There is also no difference in the gain score between men and women. Thus, despite the fact that women score lower, they have the same abilities, do just as well in the course, and learn the same amount as men. These results all seem to point to some type of bias against women in the MCI. Results in the literature suggest that the way items are worded can have an effect on the differences measured between men and women.[19,20] In the case of the MCI, this may be due to the use of context-free questions. A more detailed discussion of these results has been presented previously.[18]

Conclusions

The use of guided inquiry has potential to serve as a new approach to teaching engineering. By placing responsibility for learning more clearly on the students, but at the same time providing them with a guided approach to the material, there is an opportunity to improve learning outcomes and satisfaction of the students. Clearly, however, a number of issues remain in order for this approach to be implemented. The largest barrier is the lack of worksheet materials available. While there are published worksheets for a variety of chemistry topics,[21-23] and an organization that supports implementation within chemistry courses (see www.pogil.org), similar support does not exist within engineering. The work described here is the first step in demonstrating the possibilities of the approach for one particular engineering course, with the hope that it will lead to further exploration, implementation, and development by other engineering educators.

References

(1) Svinicki, M. D. *Learning and Motivation in the Postsecondary Classroom*; Anker Publishing Company, Inc.: Bolton, MA, 2004.

(2) Lawson, A. E. *Science Teaching and the Development of Thinking*; Wadsworth Publishing Company: Belmont, CA, 1995.

(3) Jonassen, D. H. *Computers as Mindtools for Schools, Engaging Critical Thinking, 2nd Edition*; Prentice-Hall: Upper Saddle River, NJ, 1996.

(4) Abraham, M. R.; Renner, J. W. "The Sequence of Learning Cycle Activities in High School Chemistry", *Journal of Research in Science Teaching* **1986**, *23*, 121-143.

(5) Renner, J. W.; et al. "The Importance of the Form of Student Acquisition of Data in Physics Learning Cycles", *Journal of Research in Science Teaching* **1985**, *22*, 303-325.

(6) Kolb, D. A. *Experiential Learning: Experience as the Source of Learning and Development*; Prentice Hall: Englewood Cliffs, NJ, 1984.

(7) Wankat, P. C. *The Effective, Efficient Professor*; Allyn and Bacon: Boston, 2002.

(8) Hall, D. A.; McCurdy, D. W. "A Comparison of a Biological Sciences Curriculum Study (Bscs) Laboratory and a Traditional Laboratory on Student Achievement at Two Private Liberal Arts Colleges", *Journal of Research in Science Teaching* **1990**, *27*, 625-636.

(9) Renner, J. W.; Paske, W. C. "Comparing Two Forms of Instruction in College Physics", *American Journal of Physics* **1977**, *45*, 851-859.

(10) Spencer, J. N. "New Directions in Teaching Chemistry: A Philosophical and Pedagogical Basis", *Journal of Chemical Education* **1999**, *76*, 566-569.

(11) Prince, M. J.; Felder, R. M. "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases", *Journal of Engineering Education* **2006**, *95*, 123-138.

(12) Farrell, J. J.; Moog, R. S.; Spencer, J. N. "A Guided Inquiry General Chemistry Course", *Journal of Chemical Education* **1999**, *76*, 570-574.

(13) Hanson, D.; Wolfskill, T. "Process Workshops - a New Model for Instruction", *Journal of Chemical Education* **2000**, *77*, 120-130.

(14) Krause, S.; Decker, J. C.; Niska, J.; Alford, T.; Griffin, R. "Identifying Student Misconceptions in Introductory Materials Engineering Classes", *Proceedings, ASEE Annual Conference* **2003**.

(15) Krause, S.; Tasooji, A.; Griffin, R. "Origins of Misconceptions in a Materials Concept Inventory from Student Focus Groups", *Proceedings, ASEE Annual Conference* **2004**.

(16) "Student Assessment of Learning Gains"http://www.wcer.wisc.edu/salgains/instructor/, accessed

(17) Seymour, E.; Wiese, D. J.; Hunter, A.-B.; Daffinrud, S. M. "Creating a Better Mousetrap: On-Line Student Assessment of Their Learning Gains", *paper presented at American Chemical Society National Meeting* **2000**, http://www.wcer.wisc.edu/salgains/ftp/SALGPaperPresentationAtACS.pdf.
(18) Douglas, E. P. "Effects of Sex and Ethnicity on Performance on the Materials Concept Inventory", *Proceedings, American Society for Engineering Education Annual Conference* **2007**.
(19) McCullough, L. "Gender, Context, and Physics Assessment", *Journal of International Women's Studies* **2004**, *5*, 20-30.
(20) Rennie, L. J.; Parker, L. H. "Equitable Measurement of Achievement in Physics: High School Students' Responses to Assessment Tasks in Different Formats and Contexts", *Journal of Women and Minorities in Science and Engineering* **1998**, *4*, 113-127.
(21) Moog, R. S.; Farrell, J. J. *Chemistry, a Guided Inquiry, 2nd Edition*; John Wiley & Sons: New York, 2002.
(22) Spencer, J. N.; Moog, R. S.; Farrell, J. J. *Physical Chemistry: A Guided Inquiry. Thermodynamics*; Houghton Mifflin Company: Boston, 2004.
(23) Straumanis, A. *Organic Chemistry: A Guided Inquiry*; Houghton Mifflin Company: Boston, 2004.