Use of Process Oriented Guided Inquiry Learning for Introduction to Materials

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Process Oriented Guided Inquiry Learning in the Engineering Classroom

Introduction

Active learning approaches are being used more extensively in engineering education as the literature base on their effectiveness continues to grow.[1-12] In addition to the empirical research showing improvement on various learning outcomes, the use of active learning is also supported by cognitive models of learning.[12,13] The key point to note about these models 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 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.[14] 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, this model of information processing underlies the constructivist approach to learning. Constructivism 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."[15] One practical application of how to apply the constructivist approach is through the learning cycle model.[14,16,17] (Note that this learning cycle model is different from Kolb's learning cycle,[1,18] 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.[16,19,20] This approach is most powerful when the learners themselves invent the concepts (rather than having it told to them). This educational approach is the basis for constructivism. In a constructivist approach the roles of the instructor and students are quite different from a traditional class.[21]

This paper focuses specifically on Process Oriented Guided Inquiry Learning (POGIL). In a standard POGIL 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.[22,23] Farrell et al. have described the roles of students within the groups and the class procedures.[22]

POGIL was originally developed for the chemistry curriculum, and thus most of the published materials[24-27] and studies of its use[22,23] have occurred within chemistry. A recent textbook provides POGIL materials for materials engineering,[28] providing the first opportunity to understand how POGIL can be implemented in engineering. In this paper we address the following research questions:

1. Does POGIL lead to increased understanding of materials engineering concepts compared to a lecture class
2. How is POGIL implemented across diverse types of universities?

Question 1 is examined through a quantitative component in which POGIL was implemented at four different institutions in the US and gains on the Materials Concept Inventory were compared to lecture classes. For question 2 a content analysis was conducted on course materials used by the instructors and student reflections from the end of the semester.

Methodology

POGIL was used in the undergraduate Introduction to Materials Engineering classes at four different institutions in the US. These institutions were purposively selected to represent four different types of institutional contexts. Table 1 summarizes their characteristics.

Table 1: Institutional characteristics

Institution	Institution type
Research University	Large, public, research-intensive university.
Emerging Research University	Medium-sized public university. Primary undergraduate teaching focus transitioning to research-intensive.
Minority University	Medium-sized, public university with large African-American population. It is classified as a Historically Black College or University (HBCU).
Liberal Arts University	Small, selective liberal arts university focused on teaching.

At each of these institutions one section of the Introduction to Materials Engineering class was taught using the available POGIL text.[28] Instructors were not required to use this text in any particular way or for any particular proportion of the course; they were free to use the textbook in any way they felt best met the needs of the class. All instructors did attend a formal workshop on how to implement POGIL before teaching the class. Each institution also had a control section in which the same course was taught by a different instructor using a different textbook. These control sections would typically be classified as primarily lecture.

Effectiveness of the POGIL approach was determined using the Materials Concept Inventory (MCI),[29,30] a 30 item multiple choice instrument designed to identify student misconceptions in an introductory materials engineering class. Students in both the POGIL and lecture sessions completed the MCI at the beginning and end of the semester, and the gains over the semester were compared using mixed analysis of variance (ANOVAs) and dependent t-tests.

To understand how students perceived their own learning in the POGIL class, at the beginning of the semester they identified goals for themselves. At the end of the semester they provided written reflections on those goals and the class in general. The research team also collected course materials from the POGIL instructors: course notes, slides, reading assignments, homework assignments, exams, and any other material that the instructor thought was relevant. These materials were analyzed using content analysis.[31,32] First common themes appearing in each course were identified to understand how POGIL was implemented and perceived by the students at that institution. Then the data was examined across institutions to identify common themes as well as differences.

Findings

Effectiveness of POGIL

Table 2 shows the statistics for the MCI when the results from all universities are combined, and for each university separately. Due to an administrative error, control MCI results from Minority U. are not available. Overall, there was significant gain in score for all universities combined and for each university separately in both the POGIL and lecture classes. Across all universities the gain in MCI scores was greater for the POGIL classes than for the lecture classes, at $p<.05$. However, when the results are disaggregated by university the difference in the gains between POGIL and lecture classes is significant only for Emerging Research University ($p<.01$). This difference is likely due to a greater effect size and a larger sample size resulting in greater statistical power at Emerging Research University compared to the others. However, the trend for all universities is for higher gain in POGIL classes than in lecture classes, even in those cases where this trend is not statistically significant.

Table 2: Results from MCI

	Pre-Test Mean	**Pre-Test SD**	**Pre-Test N**	**Post-Test Mean**	**Post-Test SD**	**Post-Test N**	**Gain**
All universities POGIL	10.16	3.56	225	14.49	4.22	202	4.33
All universities Lecture	9.95	2.94	226	13.23	3.82	218	3.28
Research U. POGIL	9.90	4.45	52	13.32	3.82	47	3.42
Research U. Lecture	9.66	2.81	111	12.66	3.89	101	3.00
Emerging Research U. POGIL	10.92	3.27	117	16.31	3.74	104	5.39
Emerging Research U. lecture	10.00	2.97	92	13.52	3.65	94	3.52
Minority U. POGIL	7.88	2.36	41	10.43	3.15	37	2.55
Liberal Arts U. POGIL	11.33	2.23	15	15.64	2.50	14	4.31
Liberal Arts U. Lecture	11.17	3.21	23	15.04	3.69	23	3.87

POGIL Implementation

The content analysis of instructional materials and student reflections showed the emphasis of how POGIL was implemented at each institution. Table 3 summarizes whether or not the key POGIL elements of critical thinking, teamwork, and communication were reflected in the class syllabus and activities. It can be seen that in the syllabus all instructors mentioned teamwork, but not critical thinking or communication. This is likely because the syllabi were focused on the mechanics of how the class would operate, and thus discussed teamwork in that context. Any objectives or outcomes for the classes were related to the technical content, rather than professional skills the students might gain, such as critical thinking and communication.

The use of POGIL elements in class activities were specifically related to the extent to which POGIL was used in the classes. At all but Emerging Research U. the instructors used POGIL for all of the class periods. Thus, all elements appeared throughout the entire class. In contrast, the instructor at Emerging Research U. used POGIL approximately 30% of the time, with the remaining time being used for lecture and other active learning techniques.

Table 3: Incorporation of POGIL elements in course materials

		Critical Thinking	**Teamwork**	**Communication**
Research U.	Syllabus	no	yes	no
	Class Activities	yes	yes	yes
Emerging Research U.	Syllabus	no	yes	no
	Class Activities	some	some	some
Minority U.	Syllabus	no	yes	no
	Class Activities	yes	yes	yes
Liberal Arts U.	Syllabus	no	yes	no
	Class Activities	yes	yes	yes

Student reflections at the end of the semester revealed the distinct character of each implementation. At Research U. the focus of the reflections was on the increased understanding obtained by the students. For example one student stated that, “My group has improved in its capabilities to solve the problems and understand the concepts more efficiently”. The most common comment in the reflections was that students finished the class with increased learning. They also indicated that they enjoyed the group work and felt they had improved their teamwork skills as a result of being in the class. One student noted that “we have become very comfortable in a group setting and efficient in group work”. They also found the class structure motivating and felt it helped them gain skills in communication and critical thinking.

At Emerging Research U. students primarily commented that the class helped them to see how to connect the technical content to real life problems. According to one student, “I can far more easily relate what we learned to the real world” and another student commented: “one of my goals was to understand the materials and be able to create relationships between what was learned and everyday life. This was not only let me reach my learning goals but went above and beyond”. This view reflects the unique population at this university, which consists of a large number of students who are simultaneously working in an engineering job and going to school. Thus, they see their education as a means to help them learn to solve practical problems they face in their jobs. Like Research U. they found that the POGIL activities helped them to learn the content. Interestingly, the use of POGIL for only 30% of the class allowed these students to compare lecture and POGIL. They generally stated that the lectures were not as helpful as the activities and wanted to have more opportunities for collaboration.

Students at Minority U. primarily mentioned working in groups, with a considerable difference in whether or not they saw groups as being helpful to their learning. One benefit seen of working in groups was that students helped "the group through hard spots in the class". While many students saw the importance of helping others learn and sharing knowledge, others found the groups to not be helpful. Reasons given for this lack of help were individual preferences to work on their own and a feeling that the group did not put adequate effort into collaboration. For example, one student stated: "My learning style is better suited to examples and figuring things out myself". Among those who mentioned the value of the group to learning, 15 students said working in groups added value, while 7 said it did not.

Finally, students at Liberal Arts U. were overall the most positive about using POGIL. Students explained that "the guided learning process correlates well to the way I learn" and "my mastery of the subject has increased because of the group discussions". This likely comes from the cohort in that class. At Liberal Arts U. the class was the smallest of any of the institutions and consisted of mechanical engineering students who had all taken several classes together before this class. In contrast, at the other three universities the classes were larger, students came from multiple engineering disciplines, and for the most part they did not know each other before the materials class. Thus, the camaraderie among the students at Liberal Arts U. contributed to their positive attitudes. In addition, they felt that POGIL helped them to become more active and responsible for their own learning, become better problem solvers and collaborators, and helped them to master the class content. This growth was expressed by one student saying, "I can tell how I interact with the text and my team is now different from what I have done in the beginning of the semester"

When looking across the four universities some common themes emerge, but there are also important differences. Research U. and Liberal Arts U. were the most similar. At both universities students emphasized increased learning and less need to study for exams. This similarity is likely because these two schools have higher academic requirements for admission than the other two.

In contrast, at both Emerging Research U. and Minority U. there were few comments on increased learning resulting from POGIL. At Minority U. the focus was on the benefits and limitations of group dynamics. At Emerging Research U. the focus was on how the technical content relates to applications and on class performance (e.g. grades) over learning of skills. This emphasis at Emerging Research U. reflects the student population of working professionals who are simultaneously in school. In addition, approximately 25% of these students are non-traditional, and thus have families and other life responsibilities not found in a typical classroom.

Conclusions

Quantitative results show a trend for increased learning in materials engineering POGIL classes compared to lecture classes, a finding that is consistent with what has been reported previously for chemistry classes.[22,23] In order to improve the robustness of these results we will continue to collect data in future academic years. Qualitative results on implementation show that the particular context affects how POGIL is perceived by students. When implementing POGIL, or any instructional strategy, it is important to understand the perspectives of the students and adjust accordingly, both to address their needs and to help them to go beyond what they see as important. For example, students at a university such as Emerging Research U., who are also working and have family responsibilities, need to see how the class can help them with practical problems they face on the job. Although these students saw that POGIL helped them to connect technical skills to practical problems, they apparently did not see the benefits of learning professional skills (teamwork, communication, etc.) through POGIL, which points to the need to be explicit on how such skills will benefit them in the future. Overall, this study adds to the evidence that POGIL is an approach that can be useful in a variety of disciplines and contexts.

References

1 Wankat, P. C. *The effective, efficient professor*. (Allyn and Bacon, 2002).

2 Felder, R. M. A longitudinal study of engineering student performance and retention. IV. Instructional methods. *Journal of Engineering Education* **84**, 361-367 (1995).

3 Felder, R. M., Felder, G. N. & Dietz, E. J. A longitudinal study of engineering student performance and retention. V. Comparisons with traditionally-taught students. *Journal of Engineering Education* **87**, 469-480 (1998).

4 Haller, C. R., Gallagher, V. J., Weldon, T. L. & Felder, R. M. Dynamics of peer education in cooperative learning workgroups. *Journal of Engineering Education* **89**, 285-293 (2000).

5 Demetry, C. & Groccia, J. E. A comparative assessment of students' experiences in two instructional formats of an introductory materials science course. *Journal of Engineering Education* **86**, 203-210 (1997).

6 Terenzini, P. T., Cabrera, A. F., Colbeck, C. L., Parente, J. M. & Bjorklund, S. A. Collaborative learning vs. lecture/discussion: Students' reported learning gains. *Journal of Engineering Education* **90**, 123-130 (2001).

7 Woods, D. R., Hrymak, A. N., Marshall, R. R., Wood, P. E., Crowe, C. M., Hoffman, T. W., Wright, J. D., Taylor, P. A., Woodhouse, K. A. & Bouchard, C. G. K. Developing problem solving skills: The McMaster problem solving approach. *Journal of Engineering Education* **86**, 75-91 (1997).

8 Polanco, R., Calderon, P. & Delgado, F. Effects of a problem-based learning program on engineering students' academic achievements, skills development and attitudes in a Mexican university. 21 (Mexico, 2001).

9 Deek, F. P., Kimmel, H. & McHugh, J. A. Pedagogical changes in the delivery of the first-course in computer science: Problem solving, then programming. *Journal of Engineering Education* **87**, 313-320 (1998).

10 Maskell, D. Student-based assessment in a multi-disciplinary problem-based learning environment. *Journal of Engineering Education* **88**, 237-241 (1999).

11 Harmon, T. C., Burks, G. A., Giron, J. J., Wong, W., Chung, G. K. W. K. & Baker, E. L. An interactive database supporting virtual fieldwork in an environmental engineering design project. *Journal of Engineering Education* **91**, 167-176 (2002).

12 Prince, M. J. & Felder, R. M. Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education* **95**, 123-138 (2006).

13 Svinicki, M. D. *Learning and motivation in the postsecondary classroom*. (Anker Publishing Company, Inc., 2004).

14 Lawson, A. E. *Science teaching and the development of thinking*. (Wadsworth Publishing Company, 1995).

15 Jonassen, D. H. *Computers as mindtools for schools, engaging critical thinking, 2nd edition*. (Prentice-Hall, 1996).

16 Abraham, M. R. & Renner, J. W. The sequence of learning cycle activities in high school chemistry. *Journal of Research in Science Teaching* **23**, 121-143 (1986).

17 Renner, J. W. The importance of the form of student acquisition of data in physics learning cycles. *Journal of Research in Science Teaching* **22**, 303-325 (1985).

18 Kolb, D. A. *Experiential learning: Experience as the source of learning and development*. (Prentice Hall, 1984).

19 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* **27**, 625-636 (1990).

20 Renner, J. W. & Paske, W. C. Comparing two forms of instruction in college physics. *American Journal of Physics* **45**, 851-859 (1977).

21 Spencer, J. N. New directions in teaching chemistry: A philosophical and pedagogical basis. *Journal of Chemical Education* **76**, 566-569 (1999).

22 Farrell, J. J., Moog, R. S. & Spencer, J. N. A guided inquiry general chemistry course. *Journal of Chemical Education* **76**, 570-574 (1999).

23 Hanson, D. & Wolfskill, T. Process workshops - A new model for instruction. *Journal of Chemical Education* **77**, 120-130 (2000).

24 Moog, R. S. & Farrell, J. J. *Chemistry, a guided inquiry, 2nd edition*. (John Wiley & Sons, 2002).

25 Straumanis, A. *Organic chemistry: A guided inquiry*. (Houghton Mifflin Company, 2004).

26 Spencer, J. N., Moog, R. S. & Farrell, J. J. *Physical chemistry: A guided inquiry. Thermodynamics*. (Houghton Mifflin Company, 2004).

27 Moog, R. S., Spencer, J. N. & Farrell, J. J. *Physical chemistry: A guided inquiry. Atoms, molecules, and spectroscopy*. (Houghton Mifflin Company, 2004).

28 Douglas, E. P. *Materials science and engineering: A guided inquiry*. (Pearson Education, 2014).

29 Krause, S., Decker, J. C., Niska, J., Alford, T. & Griffin, R. Identifying student misconceptions in introductory materials engineering classes. *Proceedings of the ASEE Annual Conference* (2003).

30 Krause, S., Tasooji, A. & Griffin, R. Origins of misconceptions in a materials concept inventory from student focus groups. *Proceedings of the ASEE Annual Conference* (2004).

31 Hsieh, H.-F. & Shannon, S. Three approaches to qualitative content analysis. *Qualitative Health Research* **15**, 1277-1288 (2005).

32 Mayring, P. in *A companion to qualitative research* (eds U. Flick, E. Kardorff, & I. Steinke) 266-269 (Sage, 2004).