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A Hybrid Approach to Teaching Materials Science Using POGIL and Active Learning Activities

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Abstract

The purpose of this research was to measure student learning and attitudes towards a hybrid approach to learning an introductory materials science course in engineering. The approach utilized both guided inquiry learning and active learning. Quantitative learning was measured using pre- and post- test results of the Materials Concept Inventory (MCI). Attitude surveys asking students to rank the effectiveness of the different contents of the hybrid curriculum was administered at the end of the semester. To facilitate the hybrid approach, a process oriented guided inquiry learning (POGIL) materials science text book was used in this research. In addition, class instruction included active learning activities such as in-class demonstrations, hands-on exercises and mini- presentations by students on various topics. The post- test results of the MCI scores was 43% showing an average gain of 7% compared to the pre- test results. Student attitudes towards the hybrid curriculum were positive and very well received. Students found in-class demonstrations as a means of learning very helpful over POGIL, in-class discussions, homework assignments, and mini- presentations.

Introduction

POGIL is the acronym for Process Oriented Guided Inquiry Learning and was developed at the Franklin and Marshall College to teach general chemistry [1]. Research results in the area of cognitive science on how people learn are the basis of POGIL [2]. This basis consists of 1) formation of a cooperative learning environment where students become interdependent and supportive of one another in understanding class material 2) questions that provoke students to think about new class material based upon previous knowledge that they may have. This is called “Guided Inquiry.” It is significant as it provides opportunities for students to integrate new information with old and resolve misconceptions that they may have and finally 3) students think about their thinking processes that were used to draw conclusions to the guided inquiry questions. This “thinking about thinking” is called metacognition [1]. Through metacognition students go through a self- evaluation, management, and regulation process and they realize that they are in control of their own learning process.

In a POGIL classroom, small groups of students work together to answer questions that assist them in constructing conclusions about concepts and information being taught. POGIL instruction is in many ways the opposite of traditional lectures. Where exploration of ideas and construction of new knowledge based upon prior information is limited in traditional lectures, a POGIL classroom thrives as students are afforded time to discuss new material and resolve any thinking processes that may be wrong. Furthermore, unlike traditional lectures where the instructor pushes information, a POGIL classroom depends upon students to be mentally active and have group discussions to answer the guided inquiry questions. During these student discussions, the instructor plays the role of a facilitator by providing assistance and guidance to groups that need help. Each group consists of approximately four students playing various roles to ensure learning. Common roles are manager, reader, recorder, reflector, technician, time keeper, and spoke person. Not all roles need to be utilized and throughout the semester students take turns playing various roles [3].

Motivation and Purpose

Materials Science is an undergraduate engineering course enrolled by junior level students in the Mechanical Engineering Technology Department at the University of Pittsburgh Johnstown (UPJ). It is a 3-credit course held each fall semester followed by a 1-credit laboratory during the following spring semester. When the author taught this course using a traditional lecture approach, it was noticed that students were very focused on memorizing materials science information. The students were more interested in knowing how to solve a problem rather than understanding the problem and the concepts. In addition, there was a lack of excitement and student-centered learning as evidenced by students busily taking notes while the author lectured. These observations prompted a desire to create a more student-centered learning environment.

With the author's first introduction to POGIL via a webinar at the University of Pittsburgh, POGIL seemed very appropriate in facilitating the desired change. Literature search yielded ample information on the effectiveness of POGIL in chemistry courses. However, research results of POGIL instruction in engineering and especially in materials science were very limited and thus provided further motivation for this research. The author felt more comfortable blending traditional lectures, POGIL instruction, and active learning activities to create the desired student-centered learning environment. Thus, the purpose of this research was to measure the effectiveness of using this hybrid approach in helping students learn concepts taught in an undergraduate materials science course.

Approach

In Fall 2012 the hybrid approach was implemented in a materials science course with 24 students. Active learning activities included student participation of in-class demonstrations (reference Table 1) such as: heat treatment of bobby pins with a propane torch to show how it can be made brittle and subsequently soft; heating steel music wire with a AC Variac to visually see how atoms change its crystal structures from a body centered cubic to a face centered cubic; synthesis of polymer using polyvinyl alcohol and borax solutions to learn about cross-linking; polymer fracturing of Silly Puddy^{TM} to illustrate effects of strain rate on polymeric chains ability/inability to create new bonds. Active learning also involved several mini- presentations by students throughout the semester (reference Table 2).

At the beginning of the semester, the purpose of this research was explained to the students. They were given a brief background on POGIL and student-centered learning. Many of them were already familiar with the term active learning and seemed excited about utilizing this approach. The first few class periods at the beginning of the semester was used to teach students about how a POGIL classroom functioned.

In the class of 24 students, six groups each with four members were formed. Students were assigned roles of manager, recorder, and reflector and roles were rotated every two weeks. These roles were discussed in detail and students were taught why each role was important in the POGIL learning process. They were also taught how to guide and support one another to maximize their learning experience and environment.

A POGIL based materials science text book [4] was utilized for this course. During POGIL instruction, the author would briefly lecture about the topic that each group was about to learn. Afterwards, groups used the exercises in the POGIL text book to learn in more detail about the topic. A sample POGIL exercise is shown in Figure 1. As can be seen from Figure 1, the guided inquiry questions provoke students to think about new class material based upon previous knowledge that they may have.

To measure student learning, pre- and post- Materials Concept Inventory (MCI) exams were administered. The MCI is a 30-minute, multiple choice exam that is available on-line and measures students' conceptual knowledge and reasoning. A sample MCI question regarding electrical conductivity between aluminum and glass is as follows: Aluminum is a better electrical conductor than is glass because aluminum: a) has more total electrons per volume b) has more conducting electrons per volume c) has electrons which move faster d) has electrons which move slower e) has more conducting electrons per volume and they move faster than those in glass. The topics in the MCI exams are as listed in Table 3 .

Table 1. In-class demonstrations involving student participation.

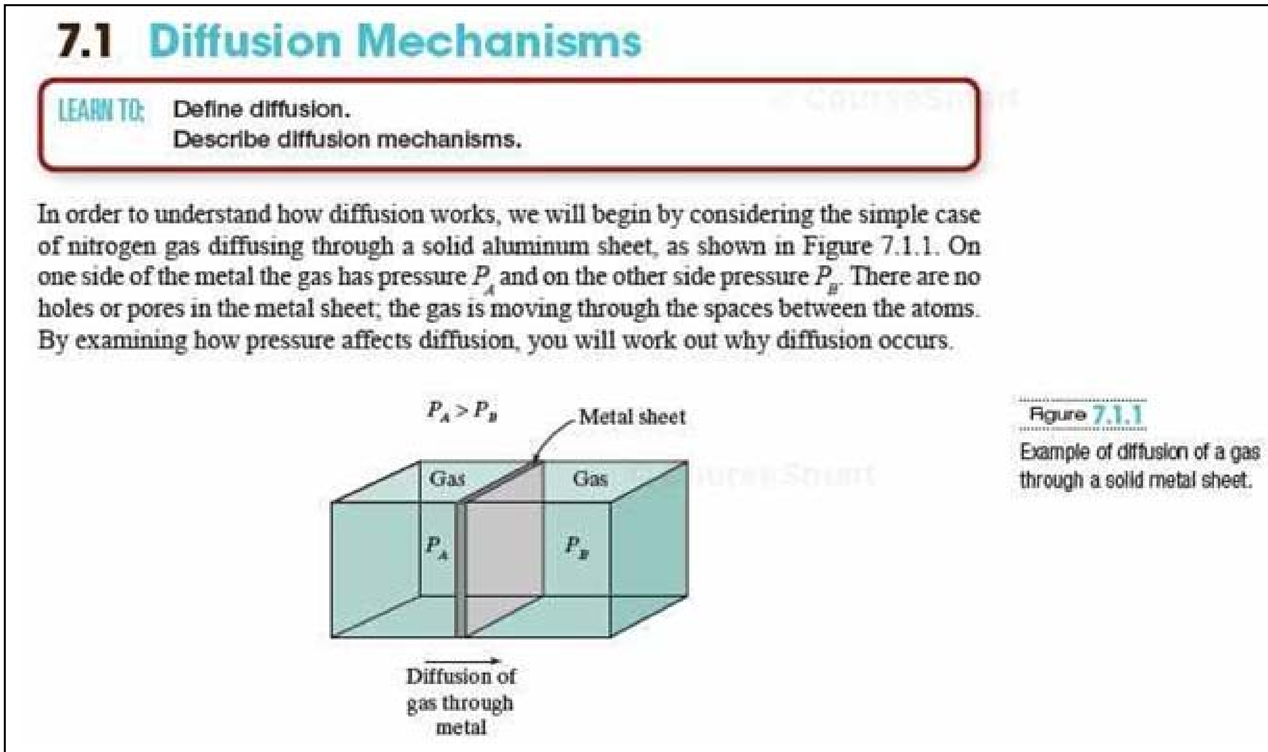
Demonstration	Materials Required	Student Participation	Concepts Being Taught
Heat treatment of bobby pins	Propane torch, water, face shield, bobby pins	A student volunteer heat bobby pins and quenches them. Half of them are distributed to the students to bend. The remaining half are reheated to temper them and distributed to the students to bend and break.	Quenching causes material to harden and become brittle. The pearlite structures changes to martensite. Tempering causes the two phase solid (ferrite and cementite) to become a single-phase solid (austenite). Tempering causes the material to soften.
Heating steel music wire	AC Variac steel music wire	Each POGIL group supply current to a steel music wire. Student groups observe volume change as the steel music wire contracts and expand.	Observe allotropic behavior of steel as it is heated: Volume changes due to crystal structure changing from BCC to FCC.
Synthesis of polymer	Polyvinyl alcohol and borax solutions, safety glasses, disposable cups, stirrers, chemical reaction formula sheet	Students use the materials to make polymer. Instructor reviews the chemical reaction and explains cross-linking.	Hydrogen bonds, cross-linking. Effects of strain rate on polymeric chains ability/inability to create new bonds.
Fracturing silly puddy	Silly Puddy™, hammer, safety glasses	Students use a hammer to fracture Silly Puddy™.	Effects of strain rate on polymeric chains ability/inability to create new bonds.
Fracturing ceramic	Ceramic mug	Instructor demonstrates the brittleness of ceramics by breaking the mug. Students inspect porosity of the mug.	Ceramics have low tensile strength. Porosity in ceramic act as stress concentrations giving ceramics very low resistance to fracture

Table 2. Mini- presentations by students.

Topics	Student Presentations	Purposes
Material properties	Each student brings in an object and discusses the material’s tensile, toughness, and electrical properties. Students take notes of these property values and compile them into three separate charts to see how different categories of materials differ in values with one another.	To engage students. To provide an overall picture of how material properties varies based upon type of material (wood, metals, ceramics, polymers). This is an introductory exercise before material properties subject is covered in depth.
Iron carbide classification	Each group is assigned to find an object that has one of the following carbon content (pure iron to 0.008 wt% C, 0.008 wt % C to 2.14 wt %C, and greater than 2.14 wt % C). They classify the iron carbide as iron, steel, or cast iron. Each group presents the effects of carbon content and heat treatment on the microstructure, hardness, and strength.	To engage students. To provide students the “big picture” of the effects of carbon content on mechanical properties.
Ceramics Presentation	Questions assigned to various groups: 1) Why do crystalline ceramics break so easily? What is it about their microstructures that make them so brittle? 2) What are the factors that influence how easily ceramics will break? 3) Why is a ceramic, in general, hard yet more brittle than metals? Compare the differences between ceramics and metals. 4) Why do aluminum oxides differ in transparency? 5) Tensile test of ceramics is not common as they are too brittle. What test is used to determine the strength of ceramics? 6) Ceramics are very hard. Why? What types of ceramics are used for abrasive applications? Why is there a hardness difference between silicon carbide and tungsten carbide? Does the crystal structure have anything to do with this difference? Does material processing affect hardness?	To engage students. This is an introductory exercise before material properties of ceramics are covered in depth.

Table 3. Conceptual knowledge and reasoning measured in the MCI [5].

1. How microstructure affects properties of ductile and brittle materials
2. How structure and properties of metal change due to defects associated with permanent deformation
3. How bonding electronic structure affects electronic, thermal, and optical properties
4. What geometry features are related to atomic arrangements
5. How bond type and strength affects properties of metals, polymers, and ceramics
6. How macroscopic rule-of-mixtures cannot be used to predict atomic-structure-based properties.Results



7.1 Diffusion Mechanisms

LEARN TO: Define diffusion.
Describe diffusion mechanisms.

In order to understand how diffusion works, we will begin by considering the simple case of nitrogen gas diffusing through a solid aluminum sheet, as shown in Figure 7.1.1. On one side of the metal the gas has pressure P_A and on the other side pressure P_B. There are no holes or pores in the metal sheet; the gas is moving through the spaces between the atoms. By examining how pressure affects diffusion, you will work out why diffusion occurs.

Figure 7.1.1
Example of diffusion of a gas through a solid metal sheet.

Corresponding guided inquiry questions:

- Which side has the greater nitrogen concentration, A or B?
- Based on Figure 7.1.1 which way does the nitrogen move through the piece of aluminum?
- If Figure 7.1.1 were changed so that the concentration of nitrogen were greater on side B than on side A, which way would the nitrogen diffuse?
- If the figure were changed so that the concentration of nitrogen were the same on side A and B, which way would the nitrogen diffuse?
- What is the driving force for nitrogen diffusion through the aluminum? *Note: By "driving force" I mean the thing that causes diffusion. If the driving force were not present diffusion would not occur.*

Figure 1. An example of guided inquiry learning. Excerpt from the Materials Science a Guided Inquiry textbook [4].

Results

The pre- and post- MCI scores were 36% (*N*=18) and 43% (*N*=16), showing a gain of 7% (reference Figure 2). These scores are comparable to other institutions [3, 4]. It is interesting to note that the three students who had gains of 23%, 30%, and 37% received the lowest pre-requisite course grades in Chemistry I of B-, C, and C-, respectively. Although the sample size is low, this observation is in agreement with literature [6] that supports the benefits of active learning for students who typically do not do well academically.

At the end of the semester part of the Learning Gains Assessment [3] obtained from www.cihub.org was administered to the students (reference Table 4). The Learning Gains Assessment asked students "How much did each of the following activities help your learning?" The in-class demonstrations had the most favorable impact on student learning as over 50% of the students felt that it help their learning "a lot". The author believes this was the case because the demonstrations were actually very fun to observe as well as contained hands-on participation that emphasized the concepts being taught very clearly. Throughout the semester, the hybrid approach allowed class discussions to occur. These discussions were usually related to erroneous conclusions being drawn by some groups. The author believes that for this reason, 33% of the students found discussions to help "a lot" towards their learning. POGIL activities, only drew 25% of the class to rate it as helping "a lot" towards their learning.

Research show conflicting results on student attitudes towards POGIL. Straumanis' multi-institutional research results [6] show 92% of the students surveyed expressed positive attitudes towards POGIL instruction. However in Douglas' research [7], engineering students seemed less satisfied with POGIL primarily due to students feeling as if they were proceeding with their learning without being reassured that they were on the right track. In this research, it can be seen that, students favored the in-class demonstrations the most over other learning activities shown in Table 4. It is possible that they didn't choose POGIL because of they may have had the negative experience of making wrong conclusions (their misconceptions) in POGIL exercises as concluded by Douglas.

At the end of the semester students were presented with three different class types in a survey: Type 1 Traditional lectures; Type 2 POGIL exercises blended with traditional lectures; Type 3 Hybrid. They were then asked "Which type of class do you think would be most effective for learning? Nine percent of the students felt that Type 1 would be most effective; another 13% thought that Type 2 would be most effective, while 78% of the students responded that Type 3 would be most effective (reference Table 5). Students' explanations of their selections are shown in Table 5.

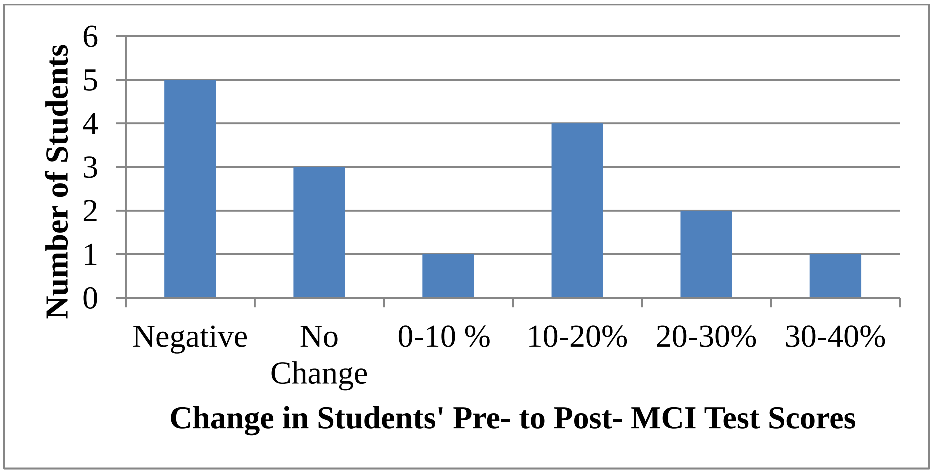


Figure 2. Student performance gains in the MCI test, *N*=16.

Table 4. Students' attitudes at the end of the semester towards various learning activities.

How much did each of the following activities help your learning?	Not Applicable	None	Not Much	Some	A Lot
Class presentations			8%	67%	25%
Discussion in class				67%	33%
POGIL activities		4%	17%	54%	25%
Classroom demonstrations			8%	42%	50%
Homework assignments			21%	46%	33%
Text book readings		17%	33%	33%	17%
Resources provided through the web	25%	8%	13%	46%	8%

Students were also asked if their group utilized the roles that were discussed at the beginning of the semester. They were also asked to rate the helpfulness of these roles using the following scale: Very helpful, Somewhat helpful, Neutral, Not very helpful, and Not at all helpful. Although 83% of the students responded that their group utilized the roles, 50% of them found the usage of roles "somewhat helpful" or "very helpful". The students provided reasons for their rating and they are shown in Table 6. Based upon their explanations, it seems as if students utilized the roles, but not in the manner that POGIL recommends. Rather than each person playing a role, they found the roles to be switched between members within a given POGIL exercise. One student noted "we switched roles and helped each other out when we didn't know something." Another student commented "Most of the group processes were a collaboration with equal balance. Roles came naturally there wasn't a need to assign them." However, several students commented that the roles provided their group "structure and organization."

Summary

The purpose of this research was to measure the effectiveness and attitudes of using a hybrid of the guided inquiry learning and active learning in teaching/learning in an undergraduate materials science course. The hybrid approach included POGIL exercises, mini- presentations by students, and student participation in in-class demonstrations. Twenty four mechanical engineering technology students participated in this research. Quantitative learning was measured using pre- and post- test results of the Materials Concept Inventory (MCI). The class average for the MCI pre- and post- tests were 36% and 43%, respectively, showing a 7% gain. Attitude survey at the end of the semester indicated that over 75% of the students felt that each of the mini- presentations, class discussions, POGIL activities, classroom demonstrations were helpful in assisting them learn materials science.

The author's experience in implementing this new hybrid curriculum was positive and plans to implement it again in Fall 2013 with some changes as follows. In addition to using the MCI to measure learning, the author plans to develop assignments or tests to measure how well students learned the basic "Concepts Being Taught" and how well the mini-presentations accomplished the "Purposes" in Table 1 and Table 2, respectively. Assignments that will require higher level of critical thinking such as case studies or open-ended project assignments are in consideration.

Table 5. Students' end of the semester responses to which types of class they preferred and why.

Type	Student Response
Type 3 Hybrid	The mix [Type 3], because the group work really gets all the students thinking & working collectively. Lecture time is definitely still necessary, though, to hear & learn from the professor. Demonstrations & presentations are fun & interactive which really benefits students who learn this way.
	Type 3 because I am a hands on/visual learner.
	Type 3 because we get to rebound off of our peers and discuss after conclusions are made
	I prefer Type 3 instruction. I enjoy the demonstrations and they taught me concepts well that I could retain. I also enjoyed the periodic research and presentations because they helped me expand my knowledge by research. Also the prep for presentations helped me to truly drive ideas into my memory.
	Type 3 because the research, presentations and demonstrations help to clear up misconceptions.
	Type 3. The group work, lecture, demonstrations at the right ratio help me to understand the concepts better.
	Type 3 b/c the groups helped to explain details, while lecture shows how to do initial problems. The research are nice b/c its not hard or intensive but helps us to learn more about specific subjects.
	The hands on environment and group work provides the opportunity for an active learning environment. The concepts are emphasized through the demos.
	Type 3 because getting to work with a group allows us to work out problems together and form good study habits. The lecture helps with learning the concepts and be able to ask questions on certain problems [to] help us learn and understand the material. The demonstrations are great because they show visually what we are learning and that helps us remember what the concept was.
	[Type 3] Demonstrations helped a lot to learn concepts. More lectures I think would be beneficial because sometimes POGIL instructions don’t work out that well.
	I think for this class “materials” a POGIL style of learning works well. The demonstrations helped to illustrate what physically happens inside of a material, because sometimes these properties are hard to visualize.
	Type 3, I believe it’s more like the real world, in that as a real engineer you usually work in a team and have other resources.
	Type 3. Group work and demonstrations make you more involved, and it is nice to hear from the professor for clarification.
	Type 3. The variation of learning helps keep interest instead of listening to lectures the whole class and working on example problems alone.
	Type 3: It allows you to use different methods for different subjects, such as [making] presentations [on] different material properties and class lecture for things like calculations.
	[Type 3]: I believe a hybrid of both would work the best. The demonstrations are extremely helpful, however a little more theory (lecture) would also help a lot.
	Type 3, because it seems to make class run smoothly.
	[Type 3] I think a mixture would be good. We could learn the info first then do group work and presentations.
Type 2 POGIL	Type 2 is most effective because the lecture really helps with the demonstrations of key topics and concepts. The group work [POGIL] also lets us help one another with understanding the material.
	Type 2 the hands on work I feel is more beneficial to my learning style.
	[Type 2] I think a mix of both types of classes would be best. I like the group work [POGIL] because when I don’t understand my group members explain it to me. However, I would like to do example problems in class because those help me more than someone explaining things to me.
Type 1 Lecture	Type 1. I’m still mainly used to this setup [and] I find it easier to learn listening to an instructor lecture.
	Type 1. I am very used to the lecture-example problem format, and I feel as though I learn more. Information is more easily organized and studies as well with this method, for me at least.

Table 6. Students' responses to the effectiveness of POGIL roles.

Very helpful	If someone didn't understand, group helped each other out. Plus gave each person responsib[ility] in [the] group.
Very helpful	It helped us to cooperate and learn the material together.
Very helpful	It's real like experience on how groups work in the work field.
Somewhat helpful	They provided some structure and organization, but we all helped each other equally.
Somewhat helpful	It kept us organized.
Somewhat helpful	We all did equal and accurate work. I found them useful.
Somewhat helpful	They helped me learn because we all could collectively figure out problems and help each other learn the material.
Somewhat helpful	It was more organized and everyone didn't have to worry about writing answers instead of listening.
Somewhat helpful	We used these roles, but we pretty much just worked better when we all contributed.
Somewhat helpful	Most of the time it ended up being a mutual effort, leader/writer sometimes wasn't necessary.
Neutral	If we would have used them more.
Neutral	B/C we switched roles and helped each other out when we didn't know something.
Neutral	Did not really stick to them as we ended up slitting duties
Neutral	It was just a big group effort, everyone worked together no matter what the role was.
Neutral	We solved problems based on individuals' strong points, not so much their assigned role.
Neutral	It was good for the first couple weeks, then it seemed like it got less organized.
Neutral	I found no advantages or disadvantages.
Not very helpful	Even though we utilized roles, each student has different understandings.
Not at all helpful	It seemed like more a pain than anything. It was easier to just all work together as equals, where anyone with the [??] sound reasoning and understanding of the topic assigns roles and reflects.
Not very helpful	Most of the group processes were a collaboration with equal balance. Roles came naturally there wasn't a need to assign them.
Not very helpful	Groups didn't take roles seriously. Students level of seriousness were incompatible.
Not very helpful	Some classes we used them, some we did not.

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