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Implementation and Assessment of Process Oriented Guided Inquiry Learning (POGIL) in Large Format Classrooms for Introduction to Materials

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Abstract: The current study presents the implementation strategy and evaluates the instructional effectiveness of process oriented guided inquiry learning (POGIL) in an introductory level materials science course over a period of four semesters. The course is required of all engineering majors in their junior year (~500 students annually). During the implementation period the use of POGIL activities expanded significantly ultimately replacing nearly all lecturing in the course. Student performance was shown to be directly correlated to class attendance and participation in POGIL activities. In addition, students' self-evaluation of learning behaviors indicate that the POGIL approach resulted in significant gains ($p<0.01$) in nearly all assessed areas over traditional lecture based coursework including: critical thinking, participation, interest, motivation, and reading. Students viewed provided model solutions, take home problem sets, concept check activities (*learning catalytics*), lecture, in-class demos, and guided inquiries as significantly supportive of learning. Finally, students found the course and instructional methods: (1) aided in seeing relevance of engineering to real-world needs, (2) increased their interest in own major, and (3) felt the material presented will be value following graduation.

Introduction: Despite a general dissatisfaction with large format stand and deliver lecturing by instructors and students alike, many engineering disciplines have been slow in implementing change through the adoption of active learning and evidence based teaching methods. In the current introductory level material science course, the transition to evidence based teaching methods was supported through a virtual community of practice (VCP) in Chemical Engineering and Materials.[1] In addition, the recent availability of topical model activities[2] and web enabled instructional technologies[3,4] has significantly reduced the barrier for the instructor in adoption and implementation of a chosen approach. The specific instructional approach investigated was the process oriented guided inquiry learning (POGIL) method.[5] POGIL is an evidenced based instructional strategy using guided inquiry, in place of lecture, to allow students to develop their own understanding of the presented material.

The foundation of the POGIL method is "guided inquiry" in which students work in small learning teams to complete activities based on the learning cycle of exploration, concept formation, and application. Using a series of guiding questions, student teams start by exploring a provided data set or physical model. The data or model provided is used to inform understanding and ultimately discover the mechanism of action or underlying phenomena responsible for the behavior being studied, i.e., "concept invention." Finally, the newly developed knowledge or concepts are applied to a related application or system. Various POGIL implementations may replace nearly all or some fraction of lecture/recitation time with POGIL activities.[5]

Instructional Method: The specific POGIL implementation in the current course employs several specific instructional/assessment strategies. Prior to each in-class activity, students are assigned a topical reading from a traditional introductory textbook.[6] The assigned reading is paired with an online quiz focusing on terminology, to be completed each week prior to the classroom sessions.

POGIL activities are the predominate feature of each class meeting. Typically each class begins with a brief topical introduction (<5 minutes), followed by the first team based POGIL activity. The majority of the POGIL activities employed are based on model activities in a recently published topical textbook.[2] For the team based activity, students are asked to self-select a learning team of 3-4 students with whom to complete the activity. During the activity, the instructor and up to three peer instructional assistants "float" between teams to help facilitate discussions and overcome common misconceptions. Near the end of each timed activity, a web-based bring your own device (BYOD) polling platform[3,4] is employed to deliver one or more "Concept Checks." These are applied conceptual or quantitative questions, intended to provide real-time formative assessment to the students and instructor. Depending on the outcome of the "Concept Checks," further team based discussion, whole class discussions, or a mini lecture may be used to address any specific areas of misunderstanding. Typically 3-5 cycles of POGIL activities, concept checks, and review/discussion are conducted during each class meeting.

Class sessions are occasionally broken up by short (5-10 minute) in-class experiments or demonstrations (preferably once per week). Example activities include: making Elmer's glue silly putty, super conductor levitation, zinc electroplating and inter-diffusion to make a "gold" penny, or observing the work hardening behavior of a paper clip. Finally, at the end of most class sessions students are asked to reflect on the material covered by completing an exit ticket (either paper copy or on-line). The exit tickets consist of three brief activities: 1) "Reflection on Learning: List three key topics or concepts presented discussed in class today?," 2) "Self-Assessment: How has your understanding of materials or materials properties changed following today's discussion?", and 3) "Muddiest-Point: What one area or concept discussed in class today are you still having trouble understanding?".

Depending on the results of the concepts checks and feedback from the exit tickets, the students may be referred to additional outside resources including: the MaterialsConcepts YouTube Channel[7], topical videos from University of Michigan[8], and/or Materials Concepts Quizlets[9]. Additional out of class practice on each topic is then gained through follow up homework assignments. These assignments focus on engineering problem solving and the application of the knowledge gained in-class. Finally, following each the four topical modules an in-class two-hour exam is given. Course grades are assigned from a combination of quiz, problem set, and exam scores. These various instructional strategies have been implemented and revised over the course of the past four semesters, with significant support in the first two semesters from the VCP program.[1] With minor modifications the approach has been implemented in classrooms with widely varied room layouts and enrollment numbers (from 70 to 145 students). All told over 850 students have been participated in the course since the first introduction of the POGIL method.

Example Materials: The majority of the POGIL activities employed are taken from a recently published topical textbook *Introduction to Materials Science and Engineering: A Guided Inquiry*, by Elliot Douglas.[2] An example guided inquiry is presented in Figure 1. Once sufficient time has elapsed for most groups to complete the assigned activity one or more applied questions (i.e., Concept Checks) are delivery using a BYOD online poling platform (e.g *Learning Catalytics* or *Socrative*; as an alternative to "clicker" systems). An example concept check, accompanying the provided guided inquiry example is provided in Figure 2.

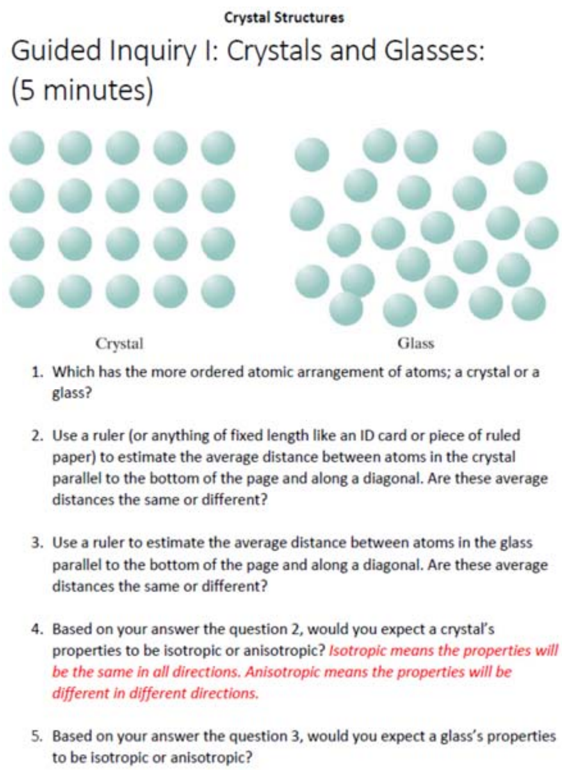

Figure 1. Example guided inquiry activity on crystals and glasses (after Douglas 2013).[2]

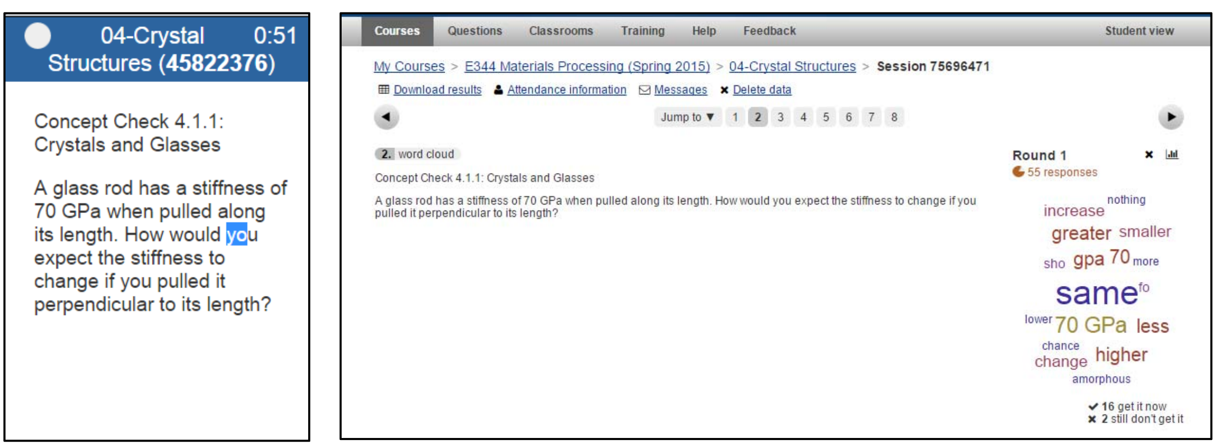

Figure 2. Learning catalytics[4] "Concept check" example for "Crystals and glasses" activity, student view (left) and instructor view and results (right).

Assessment Methods and Statistical Analyses: The effectiveness of the POGIL method was evaluated using both objective and subjective measures. The overall impact of in-class activities on student performance was evaluated by correlating attendance data to the final course grade. Attendance was determined from exit ticket data recorded by *learning catalytics*.[4] The percentage of classes attended was determined by the counting the number of exit tickets completed or attempted over the total number of exit tickets distributed over the course of the semester. Students were grouped by course grade "A", "A-", "B+", "B", "B-", and "lower". One way ANOVA was performed to determine whether attendance was a significant factor in course grade. Course grade was used as the between groups variable and attendance was the dependent variable. Post-hoc Tukey's HSD was performed to determine significant pairwise comparisons.

The attendance findings are supplemented by data obtained by two different anonymous survey tools distributed to the students. The first tool, typically distributed at end of the final class session each semester, asked students assess their behaviors and learning experience in the current POGIL learning environment and the same behaviors and learning experience in their other concurrent stand-and-deliver lecture coursework. This survey tool was developed specifically for this assessment from a tool used by the VCP to gauge faculty perceptions of student attitude and motivation.[10] Paired t-tests were used to determine which behaviors were statistically significant between the two different course formats.

The second survey tool employed (distributed at the half way point of the semester) was the students' evaluation of instructional strategies and impact (SEISI).[11,12] The SEISI tool was used to assist in identifying the specific instructional strategies students found to be most helpful and their perceptions of the overall impact of the course relative their broader education. Students were asked to rate the effectiveness of instructional strategies on a five level Likert-like scale (1-Not at All Supportive, 2-Not Supportive, 3-Nuetral, 4-Supportive, and 5-Very Supportive). Impacts were also rated on a five level Likert-like scale (1-Strongly Disagree, 2-Disagree, 3-Nuetral, 4-Agree, and 5-Strongly Agree). Effective strategies and primary impacts were identified according to the percentage of students rating an individual strategy or impact as either 4 or 5. Outcomes were ranked accordingly.

Results and Discussion: As presented above, POGIL activities and the POGIL instructional approach has been implemented in a large enrollment (75-145 students per section) introduction to materials science and engineering course. The approach has been implemented and revised over the course of five semesters and a total of nine individual course sections, attended by over 850 individual students. POGIL activities have been the primary in-class instructional component starting in the second semester following the first implementation (in the first semester roughly one third of all lectures were replaced with POGIL). Over the course of the initial implementation period instructional approaches and challenges were discussed with the support of the VCP in Chemical Engineering and Materials.[1]

In an effort to evaluate the impact of the POGIL specific instructional strategies on student performance, the possibility of a correlation between the final course grade and class attendance was studied, the results are shown in Figure 3. In the most recent fall semester the use of electronically submitted exit tickets facilitated the tracking of attendance. Students were separated into six groups according the final grade received (total subject population 278). Between group attendance was compared using ANOVA. ANOVA confirmed attendance was a significant factor in the course grade ($F(5,272)=10.12$, $p \leq 0.001$). Pairwise *post hoc* comparisons showed that students earning an "A" attended class more often than students receiving a "B+" or lower ($p \leq 0.05$). Also students receiving an "A-" attended class more often than students receiving a "B-" or lower ($p \leq 0.05$). While encouraging these findings do not necessarily demonstrate that the specific instructional methods employed (i.e., POGIL) were significant contributors to improved performance or the achievement of stated course outcomes.

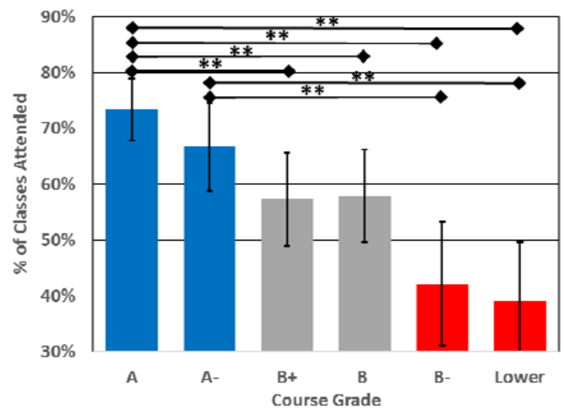

Figure 3. Class attendence was shown to be a significant factor in course grades achieved. (Significance between pairs indicated as, ** for $p<0.05$).

In order to conclusively demonstrate that the instructional methods employed were significant contributors to increased learning and improved course outcome a direct comparison between the POGIL approach and the traditional lecture approach would be desirable. However the instructor was new to the university (and prior teaching experience in a similar course involved significantly different student population), so no baseline for comparison prior to the implementation of POGIL methods exists. However, a number of learning behaviors and outcomes have been correlated with increased learning and retention[5,13]. Therefore a survey tool was developed in which students were asked to assess themselves on a number these behaviors in both the current POGIL course and their other concurrent lecture based course work.[10] The tool has been distributed at the conclusion of each of the last three semesters. Students were asked to evaluate, on a scale of 0 to 3 (i.e., 0-Disagree, 1-Disagree a little, 2-agree somewhat, and 3 agree), which of the listed behaviors they exhibited in each of the two different instructional settings, these findings are summarized in Figure 4. Positive increases in all assessed learning behaviors were reported in the POGIL classroom compared to lecture courses. In the figure, findings were ranked from top to bottom with the largest effect size between instructional settings at the top and smallest effect size at the bottom. Paired t-tests performed on each behavior indicated the reported gains in the POGIL classroom were significant relative to lecture based coursework ($N=195$, $p \leq 0.01$).

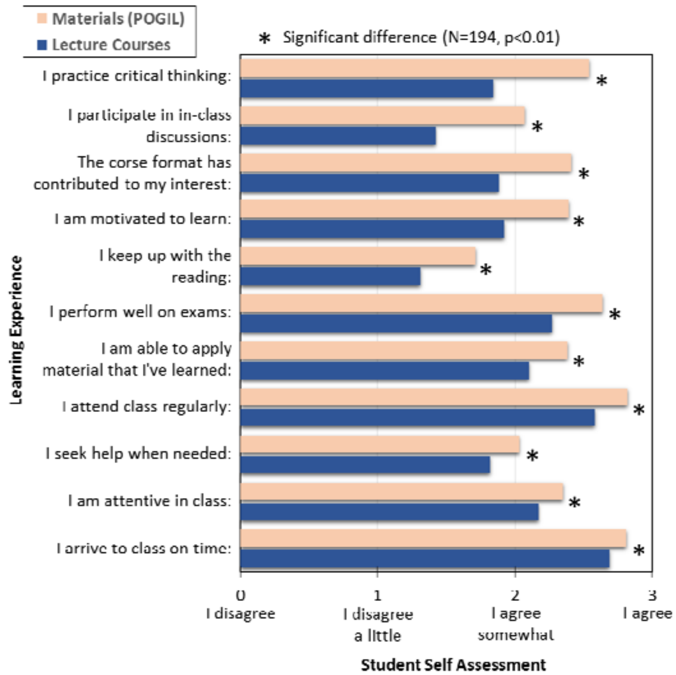

Figure 4. Significant gains in assessed behaviors were reported in the current POGIL learning environment when compared to other lecture based course work (where * indicates p<0.01).

The final assessment tool attempted to identify which specific instructional strategies the students perceived as most supportive of their learning and their perceived attainment of key course outcomes. Regarding instructional strategies, the survey tool listed ten instructional interventions employed by the instructor and asked students to assess the extent to which each strategy was supportive of their learning. Instructional strategies were ranked according the % of students indicating the intervention was either supportive or very supportive of learning, see Table I. Students ranked the provided solutions to problem sets or exams, problem sets themselves, concept check activities, lecture, in-class demos and guided inquiries respectively as most supportive of learning.

In identifying solutions and problems set as supportive of learning students have clearly tied course grade and exam performance to their self-assessment of learning. This may reflect increased emphasis on testing across the current educational system, the competitive institutional environment, and strong emphasis on GPA, rather than on long term learning and conceptual understanding of the topic. In fact, despite an initial attempts to reduce the reliance on a few high stakes exams, at the time of this survey the four exams accounted for 75% of the overall course grade. However, several POGIL specific strategies were also ranker very highly: “Learning Catalytics” (i.e., concept check activities), lecture, in-class demonstrations, and guide inquiries were also recognized as supportive of learning.

Interestingly exit tickets were seen as least supportive of learning, despite significant scientific evidence to the contrary.[11,13,14] The student dissatisfaction with the exit ticket may be due to the specific implementation used. During the period in question exit tickets were distributed online through learning catalytics, and were often made available as students were rushing to their next class. This often required students to login outside of class in-order to complete the survey. In addition, students were told their participation in the exit surveys would be used to confirm course attendance and participation for an up to 3% point bonus on their final grade (Note the final grades in the prior analysis describe in Figure 3 above were taken before these any attendance related bonus points were awarded). While providing a bonus was meant to incentivize the exit ticket activity, this linkage appears to have detracted from the primary purpose of the exercise. Instead exit tickets were viewed as another arbitrary "hoop" students had to jump through to achieve a high grade.

The final assessment presented is the student self-evaluations of course impact. Students were asked to rank outcomes on a five level scale. Survey results are presented as the percentage of students who Agreed (4) or Strongly Agreed (5) with each stated outcome, summarized in Table II. Results are ranked from the highest to lowest percentage of students agreeing with the stated outcome. Students strongly found: the course aided in seeing relevance of engineering to real-world needs, increase interest in their own (engineering) major, and that the material covered would be of value following graduation.

Table I. Student assessment of instructional strategies

Instructional Strategy	Supportive or Very Supportive
PS/Exam Solutions	87%
Problem Sets	76%
Learning Catalytics	69%
Lecture	68%
Demos	65%
Guided Inquiries	65%
Quizzes	49%
In-class TA's	49%
Textbook	46%
Exit Tickets	16%

Table II. Student assessment of course impact

Personal Impact of E344	Agree or Strongly Agree
Aided in seeing relevance of engineering to real-world needs	74%
Increased interest in own major	71%
Material presented will be of future value	65%
Would recommend course to a friend	57%
Instructional strategies increased motivation	56%
Instructional strategies should be used in other classes:	52%
Would consider taking more classes in MSE:	46%

Conclusions:

The adoption of a previously unfamiliar teaching approach, particularly in a large enrollment course, is an intimidating prospect. However, as enrollment grows it also becomes increasingly difficult to connect with students and evaluate learning in the traditional lecture format. The current effort to adopt research based strategies was precipitated by this loss of individual contact with students (coming from class sizes of typically less than 20 students) and the support of VCP program. The availability of model POGIL activities from the Douglas text[2], significantly reduced initial preparation time. In addition, it provides an evidence based model (POGIL) for the continued development of instructional modules where premade content is lacking. Based initial experiences, the development of additional POGIL modules can be significantly less time consuming than preparing traditional lecture materials. Further unlike in the traditional lecture format, the instructor receives immediate feedback from working with individual student groups during the POGIL activities and from the follow up concept check questions. This immediate feedback from the students (on the instructional materials) provides the opportunity to continuously develop and improve the delivered modules, reducing required preparation time in subsequent semesters. Overall the effort has been rewarded by a significantly improved classroom environment, increased student engagement, and high course evaluations.

On the basis of the assessments presented, the POGIL approach was effective in creating a conducive learning environment. In particular, students self-report large gains in “active” learning behaviors including: engagement, interest in the topic, and motivation to learn. This speaks to a high level of student satisfaction with the overall course format and instructional strategies employed. While the overall findings are positive, the evaluation of instructional strategies points toward several areas for continued improvement. In particular, students’ self-efficacy was clearly linked to exam performance, which they improved by relying on the provided model solutions (for exam and assigned problem sets). This potentially highlights an over reliance on exams as an assessment tool, without providing sufficient motivation for students to gain conceptual understanding and demonstrate mastery of the topic. In addition, students perceived little value in exit tickets, which are generally designed to develop critical metacognitive skills and improved self-efficacy.

These challenges are neither new nor unique to the current course. In fact, these are topics well known and widely discussed in the educational literature.[13,15] It is the plan in future POGIL implementations to move the course towards a mastery driven rather than performance driven assessment strategy. Specifically, the goal will be to reduce reliance on a few high stakes exam by instead providing multiple paths, activities, and opportunities for students build self-efficacy and demonstrate mastery of the stated learning objectives. This approach is particularly attractive in a large format classroom, where managing make up assignments, learning accommodations, and excused absences can be overwhelming. It has the added advantage of transferring more of the responsibility for learning and achievement a desired course outcome to the individual student.

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