PROPOSAL OVERVIEW AND OBJECTIVES

The way that dynamic laws arise from stochastic processes is difficult to convey to students even with the best evidence-based teaching techniques. For example, in the Process Oriented Guided Inquiry Learning (POGIL) approach, students construct their own knowledge through a learning cycle of exploration, concept invention, and application. Students progress through carefully constructed worksheets in small groups to explore a 'model' (an information rich data display), answer questions that make them think about the model, xpropose explanations for what they have explored, and then apply those concepts to further problems. As successful as POGIL is, I have found a stumbling block in my classrooms: Paper is static. Dynamic phenomena do not translate well. To understand dynamics, students must use static representations (words, pictures, figures, and equations), *to imagine* how the actual motion of the atoms and molecules leads to the macroscopic laws. It is important to solve this problem because hurdles like this one provoke student attrition from STEM disciplines, especially students with weaker mathematical backgrounds [**?**].

A long range goal of my teaching is to bring evidence based methods that are exciting and engaging to advanced physical chemistry courses. The overall objective for this proposal is to assess and revise the POGIL materials I have developed. The *central hypothesis* is that course materials that seamlessly link simulations into the class can help students to better grasp the fundamental origins of dynamic phenomena as well as improve their attitudes towards the course and material. This hypothesis is based on the exciting preliminary course materials that use QR-codes in POGIL worksheets to link to interactive simulations that run on students smart-phones, tablets, and laptops. Preliminary results show the approach is feasible (*i.e.*, it works) and students seem to enjoy the dynamic models (*i.e.*, they like it). The *rationale* of this project is that validated course materials that address this specific area will improve student learning and student attitudes can be distributed and can inform approaches to other courses. I am uniquely qualified to successfully execute this project because of my success implementing POGIL in the physical chemistry classroom and developing the first generation of in-class simulations.

The specific goals for this project are to:

- **Assess the effectiveness of a POGIL format in aiding student learning and attitudes towards the discipline.** As a baseline for comparison, the effectiveness of the POGIL approach in my classroom will be evaluated with a variety of tools, both quantitative surveys and qualitative interviews throughout the semester. No appropriate concept inventory is available. A parallel Physical Chemistry section will provide a control population. My working hypothesis is that the POGIL approach will lead to substantial differences towards understanding the course material and the discipline of chemistry in the student perception of learning gains and in affect.
- **Assess the effectiveness of dynamic POGIL materials on student attitudes and learning.** My working hypothesis is that the dynamic materials will enable students to better understand the multiple representations of dynamic phenomena (molecular, symbolic, and macroscopic). leading to gains in content mastery and, at the same time, improve their *attitudes* towards the material. The effectiveness will be assessed through post-intervention surveys and small group interviews throughout the semester.
- **Expand and refine the dynamic, interactive models based on the assessments.** The models will be expanded to be more integrated through the semester and refined based on the assessments. The simulations will encourage students to explore the interconnections between different representations of the chemistry (symbolic, macroscopic, and particulate) and to investigate how intermolecular potentials and stochastic motion lead to macroscopic, deterministic laws.

Specific Aim 1 will provide a clear understanding of the effect of the POGIL environment as I have implemented it on the student outcomes. *Specific Aim 2* will further focus on the specific interventions which introduce dynamics into the POGIL materials. Finally, *Specific Aim 3* will broaden the range of simulations and fold the understanding generated in the first two aims into generating better course materials for continuing improvement and innovation.

This project is a *creative* and *original* approach to including simulations seamlessly into an active learning environment; the comprehensive assessment will provide the evidence needed both to disseminate these materials in their current form and also to improve the approach. The *expected outcomes* of this project will be *validated* course materials, whose effectiveness has been tested. The development of this project is important at several levels. First, in my classroom, these materials will help my students learn some of the hardest material better. Second, these materials can be distributed to other sections of the same course within the Department of Chemistry. Third, it will serve as a nucleus for further incorporation of active engagement aided by technology in the broader natural sciences community at Pitt. Last, validated materials can be disseminated in the POGIL community and adopted at universities around the country. Finally, this work engages a question very timely question in the broader scholarship of teaching and learning – what to do about the technology that pours into our classrooms? Ban it? Encourage distraction [1]? Many researchers focus on the social elements of mobile technologies. This proposal's philosophy is exactly the reverse. Activities in a POGIL format are so full of *direct* student-to-student social contact – which is intently focussed on learning – that there is neither the time nor a use for socializing through computers. Instead, This project suggests that the utility in the classroom is doing what computers do well: compute, calculate, simulate, and animate. We *should* take advantage of *these* strengths.

EXPECTED SIGNIFICANCE

This project addresses a central goal of the dB-SERC – to be able *to measure* the learning amplification that our interventions create. This work also supports the dB-SERC goal of identifying and supporting the role of technology and innovation in higher education because it broadens access to "technology enabled education" [**?**], engages students in active learning, individualizes instruction through interactivity, and personalizes learning through guided inquiry. In a broader context, it also first two recommendations from the Presidential Council of Advisors on Science and Technology [2], who urge (1) "widespread adoption of empirically validated teaching practices", and (2) "discovery-based research courses". This project builds *teaching infrastructure* for "technology-enahanced education" [**?**] by disseminating the technology and techniques we develop both locally at workshops and faculty discussions, and nationwide through the POGIL project, in which I am active [**?**]). Additionally, this course transformation project will broaden the visibility of dB-SERC in the Chemistry Department at Pitt. Finally, the approach embodied in this proposal, once it has been validated, may be generalized to transforming large lecture courses in chemistry and physics.

BACKGROUND AND PRELIMINARY RESULTS

Guided inquiry methods [3**?** –6], Process Oriented Guided Inquiry Learning [6] (POGIL) for example, effectively bring active learning into the science classroom. For example, in my thermodynamics and statistical mechanics courses, students first explore a model, then construct the explanation, and then learn the standard terminology for that concept. Guided inquiry methods improve student learning outcomes and attitudes in both introductory and advanced chemistry classrooms [4].

The problem

Typical guided inquiry materials are worksheets which are *static*, but physical chemistry is *dynamic*. Static pictures are poor representations on which to develop an understanding of how molecules move: how molecular collisions create drag but also diffusion; how the kinetic energy of one particle is randomized through collisions to become heat; how the flow of heat or particles is related to a gradient of temperature or concentration. All of these points are inherently *dynamic*, which is a deep connection to the other objectives of this proposal. Students must employ complex spatiotemporal reasoning (how do things move as a function of time), to connect molecular pictures to macroscopic observables to symbolic representations of those parameters [7, 8].

The innovation

I have developed electronic course materials (HTML5 applications) for my undergraduate Physical Chemistry courses (∼35 students). The HTML5 applications run on any computer with a modern browser, (Windows, Linux, or Mac), including desktops, laptops, tablets, smartphones, and other app-capable devices. Programs are written in JavaScript, which is slower than C-code by only a factor of 3 for most numerical computation benchmarks [**?**], which makes it acceptable for scientific computations of this scale. Emscripten and typed arrays offer modest speed-ups [**?**].

These computer simulations are **integrated into guided inquiry materials** and have the potential to radically change the way students engage with the toughest concepts in physical chemistry. Paper worksheets are the proven medium for students to develop their thoughts, compose their sentences, and conduct their calculations. Integrating the computer simulations with the paper record is as straightforward as a Quick Response (QR) code (**Fig. ??, a**). All mobile devices have QR code readers available for free. Simply scanning the QR code takes the browser directly to the webpage of the model. A human readable format is also provided.

Students can interact with the dynamic models (**Fig. ??, b**) in real time. As the molecular representation evolves (upper portion of the screen), students can 'poke' the simulation and observe how the macroscopic information (bottom of the screen) responds. Three examples (**Fig. ??, b**) embody concepts that most students find very hard to master, Brownian motion, heat transport, and the structure of liquids.

Sufficient numbers of students have access to smart-phones, tablets, and laptops in class that every POGIL group had access to at least one this past spring semester. The ability to use students' devices in the classroom for learning purposes exists today and will only grow.

Moving between visualization and class discussion is seamless. Preliminary development of the applications has demonstrated dynamics of $\sim$ 500 hard spheres in two-dimensions on all platforms in portable code (JavaScript). User interactions include touch, swipe, and multitouch (pinch). These preliminary results show both the technical feasibility of the approach and the viable real-world classroom implementation. The next tasks are to assess the impact of my implementation of POGIL (*Specific Aim 1*), to assess the impact of these new models on student learning and attitudes (*Specific Aim 2*), and to refine the implementation of the models based on the results of the assessments (*Specific Aim 3*).

Assessment strategy

The efficacy of my implementation of the POGIL approach will be assessed with multiple methods. Though this is mostly 'action research', there is the possibility to share results in papers at POGIL conferences. Therefore, I will seek IRB approval.

The general strategy is to use the parallel section of Physical Chemistry 2 as a control population to assess the differences between the POGIL approach and a traditional lecture on student learning and attitudes. Provided that the instructor (TBD) approves, this could be a powerful method of testing differences between pedagogical styles. As much as possible, the relevant assessment tools will be deployed in both classes.

Nevertheless, there are two important variables to control: population bias and instructor bias. First, *population bias* could affect the quantitative assessments of learning. While student numbers in each section are in the 20–40 range, one section is a morning class and one section is an evening class. To control for the possible bias this could induce, I will use the student QPA which should be a relevant proxy for student ability. The Director of Undergraduate Studies (Bandik) will provide anonymized QPA for each section, which can be used in equivalence testing to test if the sections are similarly populated. Second, *instructor bias* could affect the differences in student attitudes. Many surveys of teaching are influenced by the "beauty contest" effect. How much students "like" a certain professor can influence the answers they give. Student Assessments of Learning Gains (SALG) instruments are a demonstrated method to elicit specific and actionable feedback from students which separates, as much as possible, the teacher from the teacher's pedagogy [9]. The SALG survey will be a comprehensive assessment of the learning gains in the class, the POGIL method, as well as individual activities (Appendix), and will be one important assessment instrument because it is known to be resistant to instructor bias.

Specific aim 1) Assess the effectiveness of my implementation of POGIL to promote student learning and attitudes

1.1 Assessment of learning

Study 1: Student self-assessment Student perception of learning gains will be assessed through an instrument developed through `salgsite.org`, which provides easy implementation and analysis of the questionnaires. I expect the self-reported results to be the clearest indication of differences in student learning.

The question areas relevant to course learning will include **1.)** understanding of class content, **2.)** increases in skills, and **3.)** integration of learning. I expect that differences in skills section will be largest between the two Physical Chemistry 2 sections – the perceived gain in the ability to explain, to solve complex problems, and to perform mathematical derivations.

Study 2: Performance data Student perception of learning gain is not always accurate. To aid in the interpretation of the self-assessments, I will coordinate with the parallel section a series of three or four "1 Minute Papers" throughout the semester which ask students to explain what they have learned. These will not be purely voluntary and not for course credit; rather, they will be couched in the context of providing feedback to the instructors for the effectiveness of the lesson. Example prompts include "Explain the relationship between multiplicities, entropy, and the approach to equilibrium using words, diagrams, and equations", and "Explain, in words, the meaning of $(\partial S/\partial U)_V = 1/T$ using words, diagrams, and equations". A rubric will be developed to score the responses for their correctness and their sophistication. The working hypothesis is that students in the active classroom will have more correct answers and be able to explain themselves in a more sophisticated manner using the language of statistical mechanics, thermodynamics, and kinetics.

1.2 Assessment of attitudes

Study 1: Pre/post assessment The effect of a POGIL pedagogy in general on class attitudes will be measured by the ASCI (V2) [10] instrument at the beginning and at the end of the course. The ASCI (V2) survey is brief (8 question) so it can unobtrusively be used both at the beginning and the end of the course. The ASCI (V2) survey will assesses students attitudes to the discipline of Physical Chemistry in two regards, both to its *intellectual accessibility* and to its *emotional satisfaction*. The working hypothesis is that the active learning environment of the POGIL classroom will lead to shifts in both categories compared with the comparison group. The purpose is to identify the changes in student attitude that the active classroom engenders.

Study 2: Student self-assessment The end of semester SALG survey will also include questions focussing on changes in attitude, specifically **1.)** class impact on attitudes, **2.)** the class structure overall, and **3.)** the class activities

Study 3: Focus groups In addition to these quantitative surveys, qualitative data will be obtained in focus group sessions. The sessions will be modelled on those of Dr. David Nero (Pitt Physics), to elicit feedback on the effectiveness of the POGIL approach to the course. Sessions will be voluntary and occur at three points in the semester. Parallel focus sessions will be run in the other Physical Chemistry 2 section, coordinated with the instructor.

Reported differences in student enjoyment and attitude towards the discipline of Physical Chemistry would confirm my hypothesis that the POGIL approach in general improves student attitudes towards learning in this discipline.

Specific aim 2) Assess the effectiveness of dynamic class materials to promote student learning and attitudes

My working hypothesis is that student learning of dynamics concepts will improve based on these simulation interventions. I will test the hypothesis through both quantitative and qualitative approaches.

2.1 Assessment of learning

Study 1: Pre/post assessment Each dynamic module will contain a pre- and post-assessment. These naturally fit in a POGIL format, and will measure that the materials have improved student mastery of the topics at hand. This will also serve as baseline data as the materials improve with successive iterations. Questions will be designed to probe the students's ability to relate static, dynamic, and symbolic representations of the material.

2.2 Assessment of attitudes

Study 1: Evaluation Specific feedback will be requested immediately after each dynamic intervention on a Likert-like scale. A brief survey will request evaluation of **1.)** the ease of use, **2.)** the perceived utility, **3.)** the effectiveness in aiding learning, **4.)** the interest level, and **5.)** a free response asking for suggestions for improvements to aid student learning.

Study 2: Focus group Specific prompts of the focus groups in the target Physical Chemistry 2 classroom will target the effectiveness of these in-class activities in supporting student learning of these concepts. Questions will aim to elicit the effectiveness, the ease of use, the approachability, and the interest level of the dynamic simulations in a more free-response setting. This more detailed feedback should aid in the interpretation of the quantitative data collected.

Specific aim 3) Expand and refine the dynamic, interactive models

3.1 Expand activities

Currently three activities have been developed and deployed (**Fig. ??**). The student reaction was positive. Nevertheless, the activities clustered at the end of the semester. Based on this initial success, the activities will be expanded both to support more of the learning goals of the class, as well as to spread the simulations more evenly through the semester. New simulations will include **1)** the dynamical approach to equilibrium (in the first week of class); **2)** the flow of heat in systems described by a discrete energy-level diagram (before the first midterm exam); and **3)** the thermodynamic cycle of an engine (before the second midterm). These three new simulations will meet the needs revealed by student misconceptions in this past semester.

3.2 Refine activities

The answers to the post-intervention questionnaires (*Specific Aim 2*) will be the input for a cycle of revision and improvement. Qualities that will be considered include: are they easy to use, do they illustrate the relationship of representations, do they distract from class, and do they help learning.

EXPECTED OUTCOMES

The three aims will together provide a route to demonstrably effective course materials. *Specific Aim 1* provides the effectiveness of the POGIL approach for this particular course. In that context, *Specific Aim 2* provides a comprehensive assessment of the strengths and weaknesses of the dynamic course materials I have developed. *Specific Aim 3* provides a pathway to incorporate the gained understanding into improved materials.

Potential problems and alternative approaches

Though unlikely, it is possible that the instructor of the parallel section of Physical Chemistry 2 will not agree to cooperate. This problem could eliminate the control population. Nevertheless, the diverse portfolio of student feedback I plan to collect is not exclusively dependent on the ability to make the case and control comparison for quiz and exam questions. A meaningful data-set should still be possible given the student self-assessment of learning gains and student feedback on the effectiveness of the dynamic displays to aid their learning.

Another potential problem, is that the student populations in the two courses may indeed be different. Recent experience in the course suggests that both courses have roughly the same proportions of A's and B's, nevertheless, the equivalence tests may fail in this year. Having unequal populations means one cannot say this study proves that POGIL is better in an absolute sense, but that is not the goal of this project. The differences in learning gains and attitude shifts should still be perceptible, and the development and refinement of course materials will still be valuable.

TIMELINE AND BUDGET JUSTIFICATION

The funds from this award will go to dedicated time during summer 2015 to prepare the new simulations and the assessment tools (surveys, questionnaires, rubrics for marking free-response questions, and focus group preparation) (0.5 month summer salary). The project will support two graduate students (1 month effort each). I will mentor the graduate students in evidence-based teaching and assessment methods. The students will then get hands-on experience designing and evaluating the pre- and post-assessments for these interventions and participating in a focus group session (Spring of 2016). An undergraduate programmer will revise and enhance the simulations in Fall 2015 ($10 / hour, 10 hours / week, 15 weeks).

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