Running head: INTRODUCTORY STEM COURSES

Principles of Good Practice in Introductory STEM Courses: Listening to the Voices of Faculty and Students

Gina A. Garcia, Josephine A. Gasiewski, Sylvia Hurtado

University of California, Los Angeles

Association for the Study of Higher Education
November, 2011
Charlotte, North Carolina

Contact: Gina A. Garcia, (310) 825-1925, ginaanngarcia@ucla.edu

This study was made possible by the support of the National Institute of General Medical Sciences, NIH Grant Numbers 1 R01 GMO71968-01 and R01 GMO71968-05 as well as the National Science Foundation, NSF Grant Number 0757076. This independent research and the views expressed here do not indicate endorsement by the sponsors.

Introduction

Since the early 1990s, there has been a focus on the pedagogical practices of introductory science, technology, engineering, and mathematics (STEM) courses. Researchers initially criticized these courses for their large class sizes, lack of engaging pedagogy, and encouragement of passive learning (e.g., Gainen, 1995; Seymour & Hewitt, 1997; Tobias, 1990). This criticism led to an abundance of studies, often conducted by the research scientists teaching these courses, which examine the curriculum, active learning strategies, and student learning assessment in introductory STEM courses. These studies, when taken as a whole, highlight a series of good practices for teaching and learning within introductory STEM courses, including collaborative learning (Peters, 2005), student response systems (Preszler, Dawe, Shuster, & Shuster, 2007) and Web-enhanced interactive pedagogy (McDaniel, Lister, Hanna, & Roy, 2007). Despite these isolated attempts at transforming scientific pedagogy, widespread change in the nature of science teaching is yet to be realized (Handelsman et al., 2004).

Recent reports indicate that faculty, in general, are using more student-centered approaches to teaching, including cooperative learning, and decreasing their use of extensive lecturing in class (DeAngelo, Hurtado, Pryor, Kelly, Santos, & Korn, 2009). The use of student response systems, in particular, is more common among faculty in the natural sciences when compared to other disciplines (DeAngelo et al., 2009). Nonetheless, colleges and universities continue to suffer from low STEM bachelor's degree completion rates (HERI, 2010), which may be attributed to the pedagogical practices of introductory STEM courses (Seymour & Hewitt, 1997). Scientists at research universities have been slow to reform their teaching, often relying on lectures that fail to foster conceptual understanding and scientific reasoning (Handelsman et al., 2004). Alberts (2005) argues that "very few students are exposed to science curricula that allow them to explore the world in the way that working scientists do" (p. 739). Furthermore, he contends that unless the curricula in introductory science courses are redesigned in order to expose students to the discovery process of science, talented scientists may continue to be lost in the early years of undergraduate education (Alberts, 2005). McWilliam, Poronnik, and Taylor (2008) expand this argument by stating that "to continue to insist on some outdated notion of disciplinary purity uncontaminated by design or dialogue is to ensure that the flight from science continues unabated" (p. 232). They stress the importance of maintaining the core science content while pushing the boundaries of creative pedagogies that allow the scientists of tomorrow to be competitive within an environment that demands creativity and innovation (McWilliam et al., 2008).

Although scientists agree that widespread curricular change is still necessary in introductory STEM courses (Alberts, 2005; DeHaan, 2005; Handelsman et al., 2004; McWilliam et al., 2008) there is a need to continually examine pedagogical practices that are effective in engaging students, enhancing scientific knowledge, and developing students' habits of the mind for scientific inquiry. The purpose of this study, therefore, is to highlight the ways in which undergraduate students and university professors at eight institutions make meaning of good teaching practices in introductory STEM courses. We utilize both the voices of students and faculty in order to better understand their experiences in these courses, as strong qualitative classroom-based educational research can and should engage the voices and the perspectives of all the individuals involved in the practice (Kemmis, 2006). While students are typically tested, surveyed, observed and interviewed, rather than treated as active agents in the research process (Leitch et al., 2007; Niemi, 2010; O'Brien & Moules, 2007), our aim is to give voices to all the individuals involved in the pedagogical relationship despite the power differentials in the classroom setting. As suggested by Chickering and Gamson (1987), students and faculty have equal roles in ensuring that good practices in undergraduate teaching are espoused and employed at the university level, and we believe that further evaluation of these practices is necessary in order to better understand effective teaching and learning within introductory STEM courses.

Literature Review

Since the call for improving STEM undergraduate education in the 1990's, evidence suggests that faculty teaching introductory STEM courses have experimented with a number of innovative strategies and techniques for improving learning. Froyd (2008) outlined eight promising practices for STEM education and evaluated them based on ease of implementation and influence on student learning. The eight practices are as follows: (1) prepare a set of learning outcomes, (2) organize students in small groups, (3) organize students in learning communities, (4) scenario-based content organization, (5) provide students feedback through systematic formative assessment, (6) design in-class activities to actively engage students, (7) undergraduate research, and (8) faculty-initiated approaches to student-faculty interactions. Some of the strategies suggested by Froyd (2008) have been tested in the classroom setting and carefully documented.

Cooperative learning in small groups. Approaches to organizing students in small groups vary tremendously but can be an effective way of increasing learning in introductory STEM courses (Froyd, 2008). A meta-analysis of the effects of small group learning in STEM courses revealed that this technique promotes academic achievement, more favorable attitudes toward learning, and increased persistence through STEM (Springer, Stanne, & Donovan, 1999). More recent studies have continued to show positive effects of cooperative techniques used inside the classroom. Knight and Wood (2005) found that by incorporating cooperative problem solving and student participation activities in a biology class, students realized increased learning gains and higher levels of conceptual understanding. Zeilik and Morris (2004) discovered that cooperative quizzes in an introductory astronomy course, which allowed students to discuss their quiz results with peers in order to debate the answers before retaking the quiz, increased individual test scores for students. Cooperative learning groups in an introductory biology course were also found to decrease course failure rates at one Minority Serving Institution (MSI) (Peters, 2005).

Supplemental instruction (SI) has also been widely recognized as an effective technique for learning in introductory STEM courses (e.g., Bowles, McCoy, & Bates, 2008; Ramirez, 1997). Villarejo, Barlow, Kogan, Veazey, and Sweeney (2008) found that alumni of the Biology Undergraduate Scholars Program cited SI as the most important academic enrichment activity that they participated in while in college. Rath, Peterfreund, Xenos, Bayliss, and Carnal (2008) found that students, and in particular underrepresented students, who participated in SI performed better in their introductory biology course and graduated in higher numbers than those that did not participate in SI.

Active learning strategies. Several active learning techniques have also been used within introductory STEM courses. One, in particular, is the use of student response systems or "clickers." Clickers have been found to increase students' attentiveness and alertness in class (Nagy-Shadman & Desrochers, 2008), improve exam scores (Freeman et al., 2007; Preszler et al., 2007), and increase course attendance (Caldwell, 2007). Clickers have the potential to increase students' understanding of course content since they provide immediate signals that allow professors to assess students' understanding of the material (Caldwell, 2007; Crossgrove &

Curran, 2008). Froyd (2008) suggests that this is effective because it allows professors to provide students with timely feedback through systematic formative assessment.

Active learning strategies can also be used out-of-class (Chickering & Gamson, 1987). One example that has been tested is the use of Web-based pedagogy that combines in-class lectures with out-of-class Web-enhanced activities (McFarlin, 2008). In comparing the outcomes of a course that used Web-based pedagogy to one that only incorporated traditional teaching strategies, McFarlin (2008) found that exam grades and final course grades were significantly higher for students in the course that used Wed-based pedagogy. Similar results were found for students enrolled in a Web-based interactive biology course at Rensselaer Polytechnic Institute (McDaniel et al., 2007). Just-in-Time Teaching (JiTT) also combines traditional in-class instruction with out-of-class exercises via the Internet. JiTT has been found to encourage student-student interaction through group work and in-class discussion while prompting faculty-student interaction through warm-up activities and cooperative learning assignments (Marrs & Novak, 2004). At Indiana University Purdue University Indianapolis (IUPUI), one physics class saw a decrease in the number of D, F, and W grades after JiTT was incorporated (Marrs & Novak, 2004).

Out-of-class technology. Although technology is not widely cited by Froyd (2008) as a promising technique for teaching in introductory STEM courses, there is an abundance of evidence suggesting that out-of-class technology may be effective for learning. Podcasts, which are audio or video recordings of the lecture that are posted online for student viewing, may be one useful technique. Carle, Jaffee, and Miller (2009) found that podcasts increase students self-reported levels of engagement and academic achievement. Using a sample of nursing students, Schlairet (2010) discovered that students who reported higher levels of usage of podcasts also reported higher levels of usefulness of the podcasts in regard to learning. As suggested by some, podcasts may actually be an effective learning tool for students with different learning abilities (Campbell, 2005) and English language acquisition (Brock, 2005). This is important since Chickering and Gamson (1987) argue that good teaching practices value diverse learning styles. As a newer technique for engaging students in learning, podcasts have not been extensively tested in introductory STEM courses, but should be considered further.

The use of Web-based homework systems is also growing in popularity in introductory STEM courses. Currently there are many programs available for instructors interested in incorporating Web-based homework including WebAssign, WebCT, and WWWAssign (Bonham, Deardorff, & Beichner, 2003) and several have been tested by researchers interested in their effect on undergraduate education. Using a quasi-experimental design, Bonham et al. (2003) compared student performance in two introductory physics courses, one that used Web-based homework and one that used traditional paper-based homework, and found no significant difference in academic performance based on the medium of homework. Allain and Williams (2006) compared four sections of an introductory astronomy course and found similar results in that there was no significant difference in conceptual understanding or test scores based on the use of online homework; however, the use of online homework did increase students self-reported time spent outside of class. Zerr (2007) also used a quasi-experimental design to compare students enrolled in a first-semester calculus course that used online homework versus one that did not and found positive outcomes including high levels of satisfaction with the online system and higher levels of engagement with the course material. These results indicate that students may desire prompt feedback and may be more engaged in course material when using Web-based systems but it may not influence overall performance in the course.

Considering the wealth of research that has been focused on good teaching practices in STEM undergraduate education, we found a dearth of qualitative research that examines this topic. The main purpose of this study is to examine how faculty and undergraduate students in STEM introductory courses define and make sense of good instructional practices. We used data collected from a series of faulty interviews and student focus groups that provided the participants with a voice that emerged from the research. Guided by the extant literature and the framework laid out by Froyd (2008), we assessed good practices for teaching and learning in STEM courses at eight diverse institutions.

Methodology

The data utilized in this study are part of a larger, multi-phased project sponsored by the National Institutes of Health (NIH) focusing on innovative techniques in introductory STEM courses. We purposefully selected eight institutions based upon high levels of classroom innovation occurring on their campus and conducted interviews and focus groups with faculty and students. The eight universities are located across the United States and include: one Hispanic serving institution (HSI), one historically Black college/university (HBCU), and six predominantly White institutions (PWI). Of these institutions, four are publically funded, while four are privately funded. We include a chart summarizing key characteristics of each institution in Appendix A, where we report the full time enrollment, funding, predominant racial designation, Carnegie Classification, region, SAT selectivity measure, annual research dollars, and student sample size. Yet when reporting student quotes we include only the institutional descriptors of geographic location, public vs. private, and Carnegie classification to provide the reader with an identifier based on context.

In sum, 41 focus groups were conducted over a five-month time span, from October 2010 to February 2011, with 239 student participants from the eight universities. The student focus groups consisted of students enrolled in introductory STEM courses between Spring 2010 and Spring 2011. Interviews ranged from 60 to 90 minutes and were conducted with two to ten participants per session, averaging five focus groups per campus. We asked students to describe their experiences in introductory STEM courses through a series of nine main questions and corresponding probes, centering around student motivation, course structure, learning, instruction, and assessment, allowing their responses to dictate the order with which we asked the questions. The student sample included 14% African Americans, 54% Whites, 8% Latino/as, 21% Asian Americans, and 3% Native American; 62% were women; 42% were freshmen, 33% sophomores, 18% juniors, and 1% seniors; 30% of the student sample described themselves as pre-med, while another 4% described themselves as pre-dental.

In addition to the student focus groups, we conducted 25 in-depth interviews with faculty members across the eight institutions. Interviews were conducted during the same time span as the focus groups. Every faculty member associated with the introductory courses sampled for the study was invited to participate, yet only 25 individuals agreed to be interviewed. Thus our faculty sample is based upon self-selection. Faculty members in the sample teach introductory courses in various disciplines including chemistry (n=10), biology (n=9), mathematics (n=5), and engineering (n=1). Years of teaching ranged from two for the newest faculty members to forty years for the most experienced. Through a series of seven main questions and corresponding probes, we asked them to describe their introductory STEM course including goals and objectives, pedagogical approaches, structure, forms of assessment, and institutional support for teaching.

For both in-depth interviews and student focus groups, we utilized a semi-structured interview technique that allowed us to respond "to the situation at hand, to the emerging worldview of the respondent, and to new ideas on the topic" (Merriam, 1998). Maxwell (2005) suggests that this technique increases the "internal validity and contextual understanding and is particularly useful in revealing the processes that led to specific outcomes" (p. 80). Prior to the interviews, participants were asked to complete a brief biographical questionnaire, which gathered data on a range of relevant background characteristics (e.g., demographic information, educational attainment, and research experience). All interviews were digitally recorded, transcribed verbatim by a professional transcription company, checked for accuracy, and loaded into NVivo8 qualitative software.

In order to develop the coding architecture utilized in NVivo, each transcript was open coded by examining the raw data and identifying salient themes supported by the text. This constant comparative approach followed an inductive process of narrowing from particular (text segments) to larger themes while allowing the researcher to attempt "to 'saturate' the categories—to look for instances that represent the category and to continue looking until the new information does not provide further insight into the category" (Creswell, 2007, pp. 150-151). Our team of six researchers each read transcripts from two institutions, gathering and comparing themes across focus groups/interviews and institutions, which also enabled analytical triangulation (Patton, 2002). Once we determined that we had reached saturation in generating themes, we developed several iterations of coding schemes, wherein codes were created, expanded, defined, and refined. These categories/themes in the raw data were then labeled as "nodes." Six researchers thematically coded three randomly-selected sections of text and inter-coder reliability ratings consistently ranged from between 80-85 percent (Miles & Huberman, 1994). Following inter-coder reliability exercises, the coding was re-validated and we were able to add new codes and sub-codes where necessary. Once the coding structures were finalized in NVivo8, we utilized 22 primary nodes, 114 secondary nodes, and 14 tertiary nodes for the student data, and 15 primary nodes, 71 secondary nodes, and 19 tertiary nodes for the faculty data. The data selected were stored there under the node and the link to the full record was maintained. Queries were run linking participant attributes with coding references. After bins of relevant data were created, we re-read the data repeatedly in order to solidify our understanding and see connections amongst the categories.

Through this process themes began to emerge in relation to how students and faculty make sense of their instructional experiences in introductory classrooms. This inductive approach began by constructing first the individual institutional cases, and individually writing them up. As we explored these themes from both vantage points, looking for areas of convergence and divergence, we began our cross case analysis, as the main activity of cross-case analysis is reading the case reports and applying their findings of situated experience to the main research question (Patton, 2002). In this way we looked for patterns and themes that cut across the institutions, then summarily over institutional types. We were then able to create and modify our comparative understanding based on each case. The purpose of our analyses and resultant findings then shifts from the exploration of individual cases to making more broad comparisons (Stake, 2006).

Limitations

It is critical to note that the students who participated in the focus group interviews were not necessarily enrolled in the classes taught by the professors who agreed to be interviewed. Because of this limitation, we cannot make direct comparisons between groups, but rather begin to uncover the teaching and learning context at each institution more broadly. Additionally, as Appendix A reveals, the focus groups ranged greatly from as low 16 students at one institution to as high as 52 students at another. This wide range in sample size was due to the number of students who agreed to participate and ended up attending the focus groups, despite the same recruiting efforts at each institution. This obviously resulted in a great differential in the amount of data available for analyses. Finally, we realize that interviewing only 3-4 faculty members per institution limits our ability to discuss faculty perspectives, but unfortunately, only a limited number of individuals were willing to be interviewed.

Findings

With these limitations in mind, in the following section we report findings related to the ways in which faculty and undergraduate students in STEM introductory courses define and make sense of good instructional practices at select institutions. We present first student level data, followed by faculty data, comparing and contrasting areas of convergence and divergence.

Southwestern Private Research University Students

Formal Classroom Techniques. Introductory STEM courses at Southwestern Private Research University enroll between 100-300 students. Within the context of the lecture, the students stressed that the most effective professors make the content less abstract by making it applicable to the real world. They said that this technique not only keeps them interested but it also provides context for the material, which ultimately helps them to remember it. One student mentioned that her ecology professor uses examples from her ongoing research on turtles, while another said that his biology professor has students look up scientific journals on particular subjects that they discuss in class. As suggested by Karl, when professors make the content more relevant and practical, it is also more interesting.

> I've had chemistry professors and calculus professors, like classes that were really dry and potentially really boring were made a lot more interesting simply because the professor absolutely loved their subject and would relate it to all sorts of things going on in the news and just, you know, relate it to all sorts of practical things that wouldn't come up in the curriculum.

Students also said that professors at Southwestern Private Research University use clickers in introductory STEM courses, although they have mixed feelings about them. As suggested by Celina, it really depends on how effective the professor is at incorporating the clickers.

> It was based on how my Intro Biology professor did it, she basically asked questions to make sure you were keeping up with your readings, and at the end of the grading period, or the end of the semester you could get up to ten points added to your grade, based on your Clicker average…So I guess it depends on how it's used. She did it also for attendance, but, yeah, I really enjoyed it because of her class. Other classes, I don't think so.

Out-of-Class Techniques. What happens outside of the formal classroom is also important for learning. Students said that professors at Southwestern Private Research University use online homework programs, which help to promote time on task and provide opportunities to practice the material. Focus group participants stated that they like the online programs because they provide instant gratification, prompt feedback, and various means for practicing the material.

> I don't know, Biology professors, they use –Master in Biology and Master in Chemistry, those are all really helpful. You go through the material, they have videos through there, they have like tests, and quizzes, ways to memorize –they have flashcards and other techniques that help you if you actually spend time on them and they'll help you for the course. (Rocco)

Study groups are also effective as they encourage student interaction and active learning. Students at Southwestern Private Research University said that they utilize both informal, student-initiated study groups as well as formal, institutionally-supported SI. As suggested by participants, studying with other students is a preferred technique for learning because it is less intimidating than talking to the professor, engages students in conversation with one another, and helps reinforce the material by forcing them to "teach" it to one another.

> They have all the SI's, Supplemental Instruction, and they encourage you to go and actually talk about it with your peers and learn it. And a lot of the teachers encouraged us to, when we were learning it, to be able to teach it to someone else, so get into groups and actually just discuss it and teach it, *because if you can teach it then you know it*, but it was mostly lecture. (Sarah)

Context for Learning. Study groups and SI are the most salient strategies used by students at Southwestern Private Research University amid the competitive environment within the introductory STEM courses. This powerful contextual element was often attributed to the pre-medical program at Southwestern Private Research University, an institution that has a well-known medical center. Despite the competitive culture, there is also a spirit of collaboration amongst STEM students, as evidenced by the number of students who talked about the importance of studying with other students, both formally and informally. Some students suggested that the competitive culture encourages people to collaborate in order to survive. The competitive culture, however, is not as prominent within engineering courses where group projects and team assignments are common.

Southwestern Private Research University Faculty

Formal Classroom Techniques. Professors at Southwestern Private Research University described utilizing many more formal classroom techniques than the students reported experiencing. Formal classroom techniques discussed by Southwestern Private Research University professors included: working problems on the board, providing and working from skeleton class notes, class discussions, group projects, bringing in practical applications, and ELMO, which is a classroom tool that allows professors to project books, handouts, or other items they want the students to see on the screen. Although the professors did not place the same stress on practical application as the students, the use and utility of ELMO was heavily discussed by two of the three instructors interviewed, with them praising the way in which they could project the problems while facing the class and enabling further student-teacher interaction.

> ELMO's my main key. What I like about ELMO too is you're facing the class. Your back's not to them while you write on the board. You don't have the dead time of writing out the whole problem. You can spend the time talking, "Okay. What's my keyword that let's me know I'm doing a confidence interval from you?" that type of thing. I love ELMO. (Professor Alpert)

When asked how they had developed their classroom techniques, it became clear that these professors had a keen awareness of their own pedagogical strengths and weaknesses. While Professor Alpert raved about ELMO, Professor Burke felt that his lack of technological know-how was a shortcoming.

> I use an overhead projector, the modus operandi on my current instrumentation is the overhead projector. I use both reading off the page and then when that's appropriate, and then mostly just like the overhead transparencies. I learned this from my professor with whom I got my PhD. He said, 'I want the students' attention focused on what I'm saying to them and not focused on the screen up there.' I have not adapted to that very well, personally. That's a shortcoming I have is probably not using enough technology so that the students are clicking along with me.

Pedagogically speaking, however, both professors seem most concerned with keeping the students' attention on the subject while avoiding down time in the lecture. But mostly, faculty teach as they were taught.

Out-of-Class Techniques. In terms of out-of-class techniques, professors discussed referring students to the success center, holding additional office hours, recommending study groups, Blackboard, and online homework but like the students, they stressed the extreme importance of SI sessions. These sessions provide smaller spaces for students to interact more personally and delve more deeply into concepts. Although SI sessions are often run by students, Professor Burke is unique in that he runs his own.

> I have two 50 minute SI sessions on a weekly basis for each class. That goes over and above about 10 hours of office time per week. I think they probably learn more in those

> sessions than they do in the lecture classes, frankly. I prepare, usually prepare extensive notes so that they don't have to write a lot of things.

The other main out-of-class learning technique that each professor mentioned was the use of tutoring at the student success center. Through an early warning system, professors can refer students to the success center when they show signs of struggling with course content or when they do not attend classes regularly. Professors find this system useful for both themselves and their students, in that it provides them with some recourse to effectively assist struggling students with specialized resources.

> Professors can now refer students who are doing poorly or who are showing absenteeism from class, can be reported to them and they will send them an e-mail stating that I'm concerned about their performance in the class and that they should come see me or visit the success center for some counseling. (Professor Burke)

Context for Learning. As noted in the student focus groups, and confirmed by the faculty interviews, the immense number of pre-health majors at Southwestern Private Research University heavily influences the context for learning, with students being more career oriented and competitive, as Professor Austin explained.

> Most of the students are often career oriented, especially at Southwestern Private Research University. They're thinking of medical school and things. They are more into what they have to do to impress those people…It's a little bit about a special thing at Southwestern Private Research University I think, because we have a very large group of students in our science programs that are pre-med, pre-dent, things like this.

Despite the emphasis on preparing students for careers in the health sciences, and potential institutional pressures to head in a more research-oriented direction, Professors at Southwestern Private Research University feel that they are able to maintain their student-centered focus. This emphasis on student learning was further underscored by the aforementioned early warning system in place to preemptively assist struggling students through an institutionalized effort.

Southwestern Private Research University was the only institution where such a system was in place.

Southeastern Private Master's College Students

Formal Classroom Techniques. Introductory STEM courses at Southeastern Private Master's College enroll between 20- 30 students. Students said that the small class setting allows professors to utilize classroom techniques that encourage student interaction and provide hands on application. The following quotes provide a good example of how faculty members encourage group work within the formal class setting.

> We used clickers in my physics class. You can buzz in with your answer, multiple choice type deal. We actually would answer it without talking to anybody and then [we] would have like a couple minutes to talk to the people around us and then re-answer. And I think that if we got it right the second time, we'd get like half credit, or I don't remember how it worked, but—It helped a lot being able to do those problems like in a group setting and—instead of just coming to the test and answering those type of questions. (Bree)

> …a lot of my professors, I noticed recently they'll explain some sort of concept, like how blood flows through the heart, and then … get in groups of like four and … or a group can pair up, and have to explain it to one another and then I feel like it's just beneficial to me [to] understand. That's when you like realize you're not understanding it, so you can still like ask those questions in class. (Talia)

Several students mentioned that Southeastern Private Master's College promotes group work, both inside and outside the formal classroom structure, but some expressed concern that groups do not work when people do not pull their weight. Hugh conveyed this sentiment as follows:

> I think group work is effective when, like you said, obviously when you get along and they can shorten the work load, but I think a lot of times you get grouped with people that don't pull their own weight and that's kind of, that's really frustrating I feel like. And on the back I feel like, you know, you're not doing more work than you should have but, you know, it's something that you got to live with and, you know, it happens..

Out-of-Class Techniques. Students said that the physics and chemistry faculty at Southeastern Private Master's College utilize online homework systems to help students learn the material outside of the formal classroom setting. Some students mentioned that the online programs can be tedious and time-consuming but many stated that they like the programs since they are forced to practice the problems while learning the material. They also liked receiving immediate feedback on their work.

> In my chemistry class we use WebAssign, which I, I actually –It's difficult, but it's beneficial, and so it gives us practice and makes us practice and makes us know what we're doing. I find it really [helpful]. (Trish)

Context for Learning. The institutional context at Southeastern Private Master's College provides a setting for collaboration and team work, since group work is highly valued, but the environment is also competitive. Several students suggested that the pre-medical context promotes competition, which is often felt within required working groups. One student said that she worked with a group where people lied about the times they could meet with others, just to sabotage the group's success. Another mentioned that the pre-medical students only compete with themselves, but nonetheless create a competitive environment for all.

Southeastern Private Master's College Faculty

Formal Classroom Techniques. As the students expressed, professors at Southeastern Private Master's College utilize a wide range of formal classroom techniques that encourage participation and student interaction, including: student presentations, reflective writing, mini-projects, clickers, response cards, case studies, animations, and most notably team-based learning.

> I use a team-based approach in the course and so from day one, students are assigned to a team. Then they stick with that team over the entire year, you know, if they continue in engineering. They work together on mini projects throughout the semester. (Professor Carlisle)

> The whole ideas was to convert it into a team-based learning course…team-based learning where the students are divided into specific groups and there's a mechanism for doing this…they come to class, and they take an individual quiz, and then they take the

> same quiz. I've used it where they've taken the exact same quiz as a team and then there's a grading mechanism for doing all this. Then, at the end of their quizzing, which is usually the first let's say 30 minutes in the classroom period, then the remainder of the period might be used to give case studies, have them work on those. (Professor Cortez)

> I let them work on it individually and with each other. In fact, just this semester we've gotten a bunch of wipe boards, small wipe boards, and they like to work through those in little groups. I don't know if you've seen our classroom, but we have everything split up into –it's set up like a lab, so we have tables with four or five students around each table, and there's a computer at each table, so that's really nice to slap the wipe board in the middle of the table and give them different colored markers and let them go to town. (Professor Widmore)

Out-of-class techniques. Again, similarly to the students, Southeastern Private Master's College professors most often described utilizing the out-of-class technique of online homework, emphasizing the improvement in student understanding and the benefit of not having to grade homework assignments themselves.

> Mastering Physics, so yeah all the homework assignments are online, and we've seen that that's –we give a standardized test, the Force Concept Inventory at the beginning and end of the semester…they implemented the online homework in the intro classes before that, but they did some studies and found that the gain scores improved significantly with implementation of that system, plus we don't have to grade. (Professor Widmore)

Context for Learning. Faculty did not mention the same pervasive sense of competition and emphasis on pre-medical preparation as did the students. In terms of the context for learning, faculty focused more on their desire to keep classes small, and the benefit of keeping Southeastern Private Master's College a teaching-focused institution.

> Well, small classes, more personal attention and you get to know –I know all of my students' first names by the end of the first test. There was an article in the university newspaper this past week about what is the future direction, and I hope we never decide that we are heading in the primary research direction. I would like to see us stay teaching undergraduates, research with undergraduates and your own professional research as being the main factors in going along. (Professor Cortez)

Midwestern Public Research University Students

Formal Classroom Techniques. Introductory STEM classes at Midwestern Public Research University enroll between 200-400 students per section, setting the stage for lectureladen pedagogy. Despite this fact, students talked about the ways that professors make the course content applicable to the real world. For example, Jason stated:

> In Organic chemistry like a week or two ago, we were talking about anti-depressants, and like just the chemical reactions in your brain. I thought it was just really interesting because he took like a half an hour to be like, okay well this is just what's going on so you can kind of understand you know this relates to our topics. So, yeah, I find it really interesting because then you just, I guess things just start to click.

Students stated that a connection to the real world helps them to understand the purpose of science, reinforces their career decisions, and facilitates learning. Some students, however, said that it is a waste of time for professors to use real world examples that are not going to be on the test. Students also indicated that clickers are used by professors at Midwestern Public Research University, but they have mixed responses to their use. Some students indicated that the use of clickers in the classroom is only useful if they receive extra credit for participating. A few students felt that the clickers help professors to gauge the students' level of understanding during the lecture.

Out-of-Class Techniques. Students talked extensively about the ways they utilize smaller, more collaborative learning spaces that are often optional (not part of the final grade) but remain connected to the course. As suggested by MacKenzie, these spaces may be an effective way to get answers to unanswered questions from the lecture.

> And for me in my big lecture if I have a question I'll write it down, and then we have like discussions, and I'm in study groups, and there's also like they have open office hours sort of where you can just go, and ask questions, which is where I ask them.

These spaces include review sessions led by faculty members teaching the courses, discussion groups taught by graduate students, and study groups facilitated by advanced undergraduate students. Many students stated that the optional review sessions held by faculty members allow them to ask questions about the material in a smaller setting. Others opt for the discussion sections taught by graduate students since they enroll between 20-40 students, making the graduate student leader much more accessible. Those who find the discussions an effective technique for learning have graduate student instructors who work on problems with them and provide immediate feedback.

> I mean, in discussion like, our [graduate student instructor] gives us problems and we like, actually go up to the board, and like, solve 'em, so that's kind of like, I guess, a way….just to understand. Yeah, 'cuz he like, tells us whether we're wrong or not, and then explains. (Vic)

The discussion sections, however, are not helpful for all students, so others turn to study groups. A majority of the students in our focus groups regularly participate in formal study groups coordinated by the learning center on campus because they are effective, fun, and valuable.

> I think that for me, I really like the study groups, but my study group leader I don't think is very good. The benefit to me is that there's other students there that are taking the class, and so, I'll go over the problems with them, not the study group leader. And so, just sort of having a forced, I guess, way that you have to meet with people two hours every week, is really beneficial to me. (Timmy)

The following quote by Dylan summarizes the importance of finding a small, collaborative environment for learning that is outside of the formal lecture.

> I feel like in lecture you don't really learn that much. Maybe I've learned like 10% of everything that I've learned in lecture. Everything else I get from attending like, the student led study groups, and like, on my own or with friends.

The use of other out-of-class techniques, including online homework programs and podcasts, are not ubiquitous at Midwestern Public Research University, with only two students stating the online homework is helpful and no students having strong opinions about podcasts.

Context for Learning. Despite the fact that Midwestern Public Research University is a large, public research institution with a sizeable STEM population, the spirit of collaboration far outweighs the competitive culture, with a majority of the study participants raving about the collaborative environment and very few ranting about the competitive nature of STEM.

> Here at Midwestern Public Research University your peers are pretty much your support group in all your classes and just getting through school basically. (Ella)

Midwestern Public Research University Faculty

Formal Classroom Techniques: Two of the three professors interviewed described traditional lecture as their main classroom technique, with little room for innovation or active learning strategies.

> Lecture is pretty traditional. There is no PowerPoint in our lectures. There are no overheads. There is chalk and there is slate. The goal there is really to construct an argument for the day. There are some intentional things that we do there in lecture that seem really old-fashioned. I don't think lecture is improved just by speeding things up, by PowerPoints. Lecture, there are already enough problems with getting students to understand what's going on in lecture and giving them enough time to really sort of process what's going on as it comes passed them in an hour, speeding things up isn't going to improve the situation any. (Professor Eko)

However one professor recognizes the importance of active learning strategies and innovation and utilizes such techniques as clickers, hand raising, pair work, real world examples, and YouTube clips.

> I've been trying to get the lecture to be more interactive. I've been using clickers for a number of years. I've switched from clickers now to a product that another faculty member designed called Lecture Tools. It's basically instead of a clicker, they can bring a laptop. It does more things than clickers. They don't have to buy a clicker. This captures all of the things that a clicker does. I use that all the time. I try to make multiple questions where I stop talking and they have to work on something. I encourage them discussing it with their neighbor or in a group of students, and then putting in their response and then we talk about it as a class. (Professor Faraday)

This is not to say that the aforementioned professors relying mostly on lecture think that lecture is enough to fully engage students. Although their approach has been to limit in-class techniques, they instead rely on the out-of-class techniques as venues for student engagement and active learning.

> The approach that Midwestern Public Research University has taken regarding lecture—you know, lots of schools have been working ways to improve lecture. We know that lecture is good for some learning goals; it's not so good for all sorts of other learning goals. Midwestern Public Research University's approach has been to figure out what lecture is good for, what does the research say lecture is good for, and do that, and do that

> as well as we can and then add other resources to the course, to try get at some of those other learning goals. Professor Eko

Out-of-class techniques. In terms of out-of-class techniques the professors echoed the importance the students placed on smaller, more collaborative learning spaces such as discussion groups and review sessions run by graduate students.

> In terms of resources that the department is putting in, we hire often 12 or more GSI's, so it's a really expensive thing to do those discussions. We do them because we think—we already know this is such a big class. There's no way I could meet with every student personally if I wanted to. There's 400 of them and only one of me, and I'm usually teaching two other classes at the same time, so that's not gonna happen. We like the idea that they have this grad student who knows them 'cause she has—she or he will have 21 to 24 students per section. (Professor Faraday)

Additionally professors mentioned utilizing course websites, online quizzes, discussion boards, and podcasts. Unlike the students, professors feel that the podcasts are quite useful and put a good deal of thought and effort into them.

> They are enhanced podcasts. They're not video, but they do have video—they have picture content. It's sort of a reversed PowerPoint. What we did is we recorded the audio and then added these pictures of diagrams, or structures, or graphs or whatever over it. As you're watching it on your iPod, or on iTunes or whatever, under the Album Art, these pictures will come up to illustrate stuff. (Professor Eko)

Context for Learning. There were two main issues that emerged from faculty interviews regarding the context for student learning: challenges posed by large class sizes and the high motivation level evidenced by Midwestern Public Research University students, as revealed below.

> I wasn't planning to be teaching intro bio to 400 students, but that's the way life works sometimes. I think it is the most challenging kind of environment to really be a good teacher. I mean, I think if you're dedicated and your class size if 50 students to 80 students, it's pretty easy to be a good teacher. When you're dealing with several hundred in one classroom, the things that you could do in the smaller class just become more unwieldy. (Professor Faraday)

> Most of these students, a large majority, either think they're going to be premed or are premed or they think they might think about being premed. They're extraordinarily motivated students. (Professor Dawson)

Southeastern Public Master's College Students

Formal Classroom Techniques. Students in introductory STEM courses at Southeastern Public Master's College take classes that enroll between 40-50 students. Several students mentioned that their chemistry professor uses tablet PCs within the formal lecture. The tablet PC program, called Dyno, records the verbal lecture while the professor is talking and saves the slides from the presentation. Students can then download the written and audio lecture from home. One student said that the tablet PC helps to keep him focused on the lecture because it is interactive. Tamara had the following to say about the Dyno system,

> I agree, especially if you're studying for an exam or something. You can look back to it. And like for other classes that don't have that, I can, I usually record the lecture using my webcam 'cuz it's easier if I'm not feeling well or just distracted. That way I can go back to it and have all the information that the teacher said. So with Dyno, it's automatically done like that because we get the slideshow and we get what the conversation was and what the lecture was.

As suggested by Tamara, students can record the lecture themselves but the Dyno program makes it easier to capture, which may be helpful for students that do not have a webcam or other means for recording the lecture. In addition to the tablet PCs, some faculty members use the clickers in class to help students follow along. Franny's comment, however, indicates that some students push back on the in-class technology.

> Well, my class, we had clickers and the tablet and I don't think it was, I think it – if the professor took a different approach when he used them it could have been successful, but at the time I don't think it was, really they made too much of a difference. And as far as the tablets go, I think that's kind of the same. I don't really like, I would have preferred the board, the regular white board over my teacher actually doing it on a tablet. It was, it was, I don't see, I don't see the benefit of it.

Out-of-Class Techniques. At Southeastern Public Master's College, learning outside of the formal classroom occurs individually more often than in groups. Students did not mention any formal SI or institutionally supported study groups but a few said that there was tutoring available for all their introductory STEM courses. A majority of the students, however, said that they used online homework problems for their math and science classes. The online homework and book websites helped some students to learn the material, as suggested by Antone.

> Well, one of my professors, when she posts homeworks, she uses Connect 2312, which is online, so what I do is with each chapter I just keep going back and do the homework over and over again…And they have other sample problems, so I usually do that, and so I'll get like 100 on each, every time. That's, that's, I keep doing them or I go to the, my book's website and they have sample problems up there, on there, and I use those to study….Yes. They post grades on there and sometimes homework.

Context for Learning. Although the use of formal study groups was not prevalent at Southeastern Public Master's College, students said that they feel comfortable collaborating with other students. Several stated that they have a collaborative relationship with students in their lab classes and that they sometimes work together on homework outside of the class. Very few students mentioned a competitive environment at Southeastern Public Master's College.

Southeastern Public Master's College Faculty

Formal Classroom Techniques. Two of the three instructors interviewed at Southeastern Public Master's College described utilizing a range of active learning strategies to engage their students, including real world application, team teaching, in class problem solving, visualizations, think/pair/share, animations, DYNO and Tablet PCs. These instructors are particularly proactive in seeking out and employing innovation in their classroom. One professor is heavily engaged in action research and innovation, while the other obtained a technology grant for tablet PC's and the accompanying software for his classroom. Below they describe some of their formal classroom techniques.

> I think also, in addition to that, is also trying to bring in some real world applications to the information because a lot of times, they'll be like, 'Why do I need to know all these parts of the cell for? Why do I care about metabolism?' This week, we brought in an exercise on why does eating sugar make you fat so they could understand metabolism and

> how that applies to their diet and things like that because otherwise, I think they'll tend to lose interest. (Professor Fernandez)

> You have this class of 100 students, how could you possibly begin to sample what people were thinking? Here suddenly, we do have the technology to be able to do that. Now, the software Dyno became available…it allows me to record my voice along with the panels that I am showing and they are synchronized. I am thoroughly convinced that if we can use devices like this as a real time communication mode, we are going to be way ahead. The lecture thing is passé. If what we can do is enhance our communication with students that allow us to see visually, oral recordings, etcetera, we are going to be way ahead of the standard approach. (Professor Norris)

Out-of-class Techniques. Professors did not describe many out-of-class techniques except for the use of online homework programs and virtual labs. However, they seemed to utilize online programs that give students more feedback than "right" or "wrong" responses. The one professor who is not particularly engaged with bringing in innovative formal classroom techniques indicated that he told his students about other learning opportunities and resources, but that it was really up to them to seek them out and employ them.

> I encourage my students—I don't know to the extent to which they follow through on this—in general I don't think it all that much, but I encourage them to study together, to go to tutors, to go to online resources—to try to find as many different ways to, as I would say, throw mud at the wall of their brain until they find an approach that makes it stick. I don't know how well they take me up on that, but I always tell my students that if at the moment the light goes on, it was because you were listening to somebody else and not me, I will never be offended by that. (Professor Hume)

Context for Learning. All three professors expressed similar frustrations with students' lack of engagement, despite their efforts at bringing in active learning strategies and technological innovation.

> I actually give them the websites. We were going over cellular respiration, and so I'm the lab and we're going over solutions. I find the websites for them. YouTube video, I give it to them. 'Here are some that will help you out. Look at them.' They say: 'Oh, I have to look at them?' These are the ones who are telling you, 'I can't understand that.' 'Okay, if you can't understand me, listen to this. Look at this.' You find it. You give it to them. 'Oh, I can't write.' 'The pen's in your hand.' 'I can't.' You know, it's like, 'What do you want me to do?' (Professor Fernandez)

Additionally, all three the professors interviewed expressed how the students' lack of preparation affected their learning, and professors' own ability to engage them in course content. Here Professor Norris discussed how students lack of scientific language, basic scientific terms and concepts forced him to "start from scratch", and made it so that the way in which he attempted to teach did not matter.

> I find that many of the students just don't have the preparation. They don't have the language and so they find it difficult to cope. You can present it, PowerPoint presentation, one-on-one discussion and so on, but if you don't know the language, it becomes difficult to operate. It means you have to go back and start from scratch. (Professor Norris)

Northeastern Private Master's College Students

Formal Classroom Techniques. Students in introductory STEM courses at Northeastern Private Master's College enroll in formal lectures with between 100-180 students. Students stated that within the formal structure of their science courses, faculty use few innovative techniques to help them learn. Some students like the in-class clickers as a way to gauge their own learning.

> In our lectures, we have [clickers], where they put the questions up on the projector and you answer kind of like anonymously, so you can see where you stand without having to be embarrassed in front of the class to possibly have the wrong answer. So, it kinda helps you to know where you stand without embarrassing yourself…They're helpful. A lot of my friends use 'em a lot. And they actually found out that something that they thought they knew, they didn't end up knowing. So, they liked that. (Melanie)

Others, however, stated that the clickers are not useful since they do not allow enough time to process the information being presented. The calculus and physics classes at Northeastern Private Master's College have incorporated a workshop model (formally called project-based courses) that many of the STEM students have participated in. Nila describes the workshop model in the following quote.

> But yeah, I went through Project-based I, II and III, and it was usually an -- there were two workshops a week, so it'd be an hour of lecture and then a workshop, and then I had two hours of lecture one day and then the next day would be an hour of lecture and then a workshop.

As a formal part of the course, the workshop is taught by the same professor and teaching assistant that facilitate the lecture throughout the week. This provides students with a seamless learning environment that is engaging, practical, and collaborative.

> But the workshop's really helpful 'cuz we're, I was in a group with four people, and we were given like 20 problems, and we'd have to finish 15 in the hour. So we kind of split up and did them, and then at the end we'd kind of look through and see which ones we had trouble with, and we'd help each other out…and then, like, everyone would look through it to make sure they had a basic understanding of how everything worked. (Irving)

As an innovative technique for teaching and learning in math-based courses, the workshop model is popular among students at Northeastern Private Master's College and was mentioned by an overwhelming majority of participants.

Out-of-Class Techniques. In addition to the formal workshops, Northeastern Private Master's College also offers SI sessions for math and science courses. Very few students, however, talked about SI as an effective technique for learning. Several did mention that they complete online homework through Mastering Chemistry, Mastering Biology, and Mastering Physics programs, which are helpful for gaining immediate feedback and encouraging time on task.

Context for Learning. According to focus group participants, Northeastern Private Master's College is a place for technically-minded students to collaborate and learn together. Several students mentioned that it is competitive to get into the technical programs at Northeastern Private Master's College but once students are in, they tend to work together. Collaboration is encouraged by faculty since there are multiple group projects to be completed. Additionally, the institution offers special interest housing for students in a variety of majors, which fosters a collaborative work space within students' residential setting.

> When I came here I opted for a special interest housing, so I live in the house of general science. So everybody on the floor is either, has, either their major is something science-

> based. There is a couple [physician assistants]. There's a lot of chem, bio on the floor, and there are even people who are completely unrelated to the sciences in terms of majors, but they're just interested in science and want to be in that kind of community, so they're there. So in pretty much any field if anybody on the floor has a problem, there is 40 other people who are pretty much always available to help. We've always got like five or six people in the study lounge. We've got a lounge that's dedicated to doing work, and there's always a bunch of people in there who will take the time out of whatever they're doing to help you. (Donnie)

The workshops model at Northeastern Private Master's College also helps to develop cooperation among students at Northeastern Private Master's College. This context makes for an effective environment for students in introductory STEM courses at Northeastern Private Master's College.

Northeastern Private Master's College Faculty

Formal Classroom Techniques: Faculty described utilizing a range of formal classroom techniques including: clickers, visualizations, peer instructional model, and real world application, but like the students they strongly emphasized the importance and value of the project-based workshops.

> When I have the workshops, what they're doing is they're really doing peer led type instruction. There I can organize them into comparable ability groups, and then more focus my efforts on those who are needing more help within that classroom situation. This is a format that's most likely to be conducive that they're actually learning something. They're working with their cohorts who, again—peer instruction can be very helpful 'cause you tend to speak the same language, you feel perhaps less threatened in asking a question, you're not so worried about looking stupid in front of the professor. Then there's also the professor there who's got time since I'm not lecturing to go over and help when they really get stuck. Those do seem to sink in better. (Professor Linus)

Out-of-class Techniques: Like students, professors discussed their use of both mandatory and voluntary SI sessions, but again like the students, stressed the important role of online homework.

> We use Mastering Chemistry as an electronic delivery device. In Mastering Chemistry, the reason I like it is because some of the questions are the traditional end of the chapter questions, but some of the questions are tutorial. They allow students to get hints, work

> through the hints and then go back to the question. It's really built very, very nicely that way. (Professor Littleton)

Context for Learning: Despite the fact that Northeastern Private Master's College is growing as an institution from a "monolithic testosterone-laden, male, tech school and into more of a university feel" (Professor Linus) professors feel strongly that teaching and their students must remain their main focus.

> As I said, we are a place that has a deep tradition of experiential learning, deep tradition of quality teaching and most of us have the mindset that we're teachers. The growth for us or the growing pains is to have a culture which is more blended, which is more the inclusion of the scholarship and the scholarship expectations. (Professor Langner)

Professors even go so far as to structure the focus of their courses around the interests of their particular cohort of students, further emphasizing their student-centered approach.

> I asked early in the year, "What do we want to focus the class around?" I like to make it topical. Some years it's focused on environmental, some years is focused on healthcare. This year is focused more on healthcare because I think I have more biology and health science professionals in that class. I bring in then, "What's going on in the mitochondria?" We incorporate then some of the biology into the class, as much as, again, time allows. (Professor Lloyd)

Western Public Research University Students

Formal Classroom Techniques. Students in introductory STEM courses at Western Public Research University enroll in classes with 100-300 students per section. They typically attend formal lecture three times a week and discussion section once a week. As suggested by students in our focus groups, beyond straight lectures, there are minimal in-class techniques being utilized to help students learn the material. Some students said that the use of clickers helps them to pay attention in class, gauge their comprehension of the material, and receive extra points toward their grade. Brianna, however, stated that clickers are a waste of money.

> But, yeah, we did clicker questions. I think it's—I really think [the clicker] is a waste, because it's $40.00, and like we don't want to spend $40.00 on this like little clicker and get the same points that everyone else is going to get. You know what I mean, so? And

> pretty much everyone I know complains about the clicker questions, so I think they're not—I don't think they're worth it in a way. (Brianna)

Out-of-Class Techniques. Outside of the formal lecture, some professors use online homework programs, but they are not prominent. Two students mentioned that online homework programs in math and physics classes are only "semi-successful" since the programs only recognize right and wrong answers but do little to inform the student about the reasons why answers are wrong and do not allow students to provide information about the process of getting to the right answer. This is problematic in math-based courses since the process of arriving at the right answer may be just as important as the answer itself.

Additionally, some students mentioned that podcasts as their preferred technique for learning because they can skip class altogether. The podcasts are audio recordings of the daily lectures that are posted online for students to access at anytime. Some students, however, mentioned that they use the podcasts to supplement their attendance in lecture.

> Well, no, I go to class, but then, sometimes like she talks too fast, so I don't catch what she's saying and I can't like write it down, so I go back and I listen to it. And then like, I just understand it so much better. (Jen)

Context for Learning. Although few students mentioned that group work is required in their introductory STEM courses, a majority of the participants stated that they regularly study with other students in their courses and meet to discuss practice exam questions. For those that do not meet regularly with other students, it is a matter of preference in learning styles, as groups tend to distract them from learning.

> I don't know for me I could, like I'll study with one other person maybe. So like a friend is taking a class I'll go over to his house, and we'll sit on the couch, and, and do like a practice midterm, and then look at the, you know the answer sheet, and then go through it together. But I don't, at least for me I can't work in groups more then, more then just me and one other person maximum. (Fred)

The environment for learning, however, is generally welcoming, as suggested by John, "I never felt afraid to ask help from peers if I needed it."

Western Public Research University Faculty

Formal Classroom Techniques. Of the three professors we interviewed, two mainly rely on working problems on the board as their main classroom technique, and seemed to reject other strategies.

> There's only one way to learn mathematics and that's by doing it. It doesn't matter whether someone draws a beautiful picture or someone does this, someone does that, unless you just keep doing it, many, many examples, you would never do it. (Professor Pace)

The majority of the innovative, active learning strategies are undertaken by one professor who is heavily involved in her own action research and has brought a wide range of techniques to her classes including: clickers, group problem solving, visualizations, hands on demonstrations, and "think-pair-share" activities.

> I use clickers in the classroom. Many times with my clicker questions I use a think-pair-share kind of format where they do it once by themselves, then I erase the data and then ask them to talk to their neighbor. Then after they've talked to their neighbor they answer again, and I see if their answers have shifted and they see if their answers have shifted. I also have them do group exercises that they have to turn in, so they work in groups of three, four or five. (Professor Locke)

Out-of-class Techniques. Much like the student focus groups, the only out-of-class technique discussed by the professors at Western Public Research University was the use of podcasts. Professors described the negative effect it had on classroom attendance.

> Not the last class, but a few quarters ago I actually taught a class where they recorded the lectures and they posted them on-line. A lot of the students were like, "Oh, well, this is great. I don't have to go to the lecture anymore. I can just watch them on-line." I had students confess later on at the end of the quarter, it's like, "Well, I meant to watch them, but, you know, I never got around to it." It's really easy for students to put off doing what they should be doing. (Professor Black)

Context for Learning. The overall learning environment at Western Public Research University seems to emphasize research over teaching. Professor Black stated this plainly.

> I haven't actually sat in on other classes. I would have to imagine that it's probably fairly similar. Faculty, especially a research institution like Western Public Research University, we teach. That's because we have to teach. We're obligated to teach. That's not really what we're interested in doing. That's not what we put our main focus on. Our main focus is on doing research. We just were basically—I don't wanna generalize, but to some degree I think we don't put our emphasis on our teaching. There are a few faculty that are exceptions who really focus more on their teaching than on their research. Because of that, I don't think we go to any extraordinary lengths, at least not the level we should be doing.

Additionally, the professors stated that the status of Western Public Research University as a Research Intensive (RI) institution added to the overall sense of competition amongst students, and shifted the focus away from teaching.

> Western Public Research University thinks it's very important to be able to rank students, especially if they're gonna be going on to professional schools. I think it's probably one of the biggest problems that we have. Yeah it's the—I mean for especially at a [research intensive] university that everybody wants to get into, I think that that also has a very big bearing on what they do, but many of them view college as a simple—or a bachelor's degree as the hoop you have to jump through so that you can finally do what you want to do. (Professor Locke)

Western Private Master's College Students

Formal Classroom Techniques. According to students at Western Private Master's College, the average size of the formal classroom setting is between 30-70 students and the classroom environment is often interesting and relevant to the real world. Rather than focusing on the concepts, students said that professors provide practical examples that help solidify their learning. As mentioned by Tobey, "learning general concepts is good, but if you don't know how to apply it, you can't build off it or really appreciate it." The engineering classes at Western Private Master's College are project-based and practical in nature, making them particularly helpful, as suggested by Kirk.

> My Intro to Engineering class was real useful. He showed us a lot of things engineers do. It was very – like I know some of 'em were very project-based. Obviously, every engineer had to do the project, Freshman engineer. He didn't focus on that one so much though. It was mainly about like what an engineer does. And so, that was actually very cool to his lectures on all the rules and stuff, the engineers follow all the guidelines and that kinda stuff, the legal ramifications. So. I found that really interesting.

Beyond making the content interesting and providing practical examples, few in-class techniques were mentioned by students.

Out-of-Class Techniques. Although students mentioned that online homework programs are used by professors at Western Private Master's College, few students have found the programs helpful for learning. Their frustration is typically related to the lack of feedback, as mentioned by Marla.

> I'm not a big fan of it. There's no partial credit. Even if you get all the work right and just miss one step, you have no idea what you did wrong, cuz it doesn't tell you.

The most cited strategy for learning in introductory STEM courses at Western Private Master's College was the workshops. The workshops are weekly peer-led sessions offered for chemistry and biology courses. Although students stated that attendance is optional and/or for extra credit, many find them to be more effective for learning than the actual lecture. The following quotes provide a few examples:

> I think at first, it was about the extra credit for me. But then, after I saw how useful the Bio workshops were, I wanted to go back and keep on going…and then the professors are like, way up here with their theory sometimes, and you don't understand what they're talking about, but the students who lead the workshops took that class last year, so they know exactly where you are and how to explain it to you. Like, a lot of time they've had the same professor, so they know how they teach and how to understand it, and they relay that to you. (Briony)

> So, as far as that goes, I – it was my first class in the morning. I was not opposed to sleeping in and going to workshop, because the workshop would be better, it'd be a lot more hands-on, I'd learn a lot better through it. (Tobey)

Context for Learning. Students at Western Private Master's College expressed a strong sense of collaboration amongst their peers in introductory STEM courses. This collaborative environment is fostered by both students' and faculty's efforts to encourage cooperation. One student mentioned that her biology professor set up study groups for students and forced them to exchange phone numbers while the following statement by Alani provides an example of the way that students help each other:

> Yeah. It happened in my intro bio class too…This guy just found—you can Moodle. You can see the participants. He added every single one of us individually to this email, and emailed us this thing on I think it was on metabolism. It was just a really nice color pages of notes that really illustrated everything. It was a huge help. He didn't know any of us. It's just—yeah, everyone really wants to help other.

Western Private Master's College Faculty

Formal Classroom Techniques. Although the students in the focus groups exclusively discussed the formal classroom technique of professors bringing in real world application, professors also described utilizing videos, animations, working problems, and student presentations. Here Professor Verdansky describes combining the techniques of real world application and student presentations.

> For the gen bio, I do have them do a little 'In the Media' presentation where they each get up in front of the class and bring something from any media source they want that relates to the section of the book that we're in. If we're in the immunology section, they'll bring in something about that. They'll do a little mini teaching or a little mini let's make this relevant to what's going on in the world right now event, so they're each up there.

Out-of-class techniques: Faculty at Western Private Master's College focused on the same out-of-class techniques as the students in the focus groups: workshops and online homework. This quote from Professor Straume suggests that, similar to the students, the online homework programs are not highly valued at Western Private Master's College.

> Online homework—we've tried that out before. Personally I am not a fan. I think in particular because of the workshop infrastructure that we have here that the technology like solutions to get better student engagement in the course can undermine our workshop. Undermine sort of that small class size, the personal relationship with the professor. I'm trying to get the students to feel like I'm here to help. Their workshop

> leaders are here to help. I tend to resist the technological solutions because I personally don't feel like they're as effective in doing it.

Context for Learning. Two main elements became abundantly clear from interviews with professors regarding the context for learning at Western Private Master's College. First, despite the fact that the university is growing, it is critical to professors that they maintain their personal relationship with students. Secondly, faculty are keenly aware of the importance of adapting their pedagogical techniques to the diverse learning modalities of a more digital/technologically reliant generation and are embracing these innovative approaches.

> I think we do a heck of a lot with what we do have, and I do feel our faculty is very much interested in the student learning and the welfare of the students. I think the engagement has to be at a level where they can kind of connect, and part of that I also think is they haven't been training their brain the same way that I think I was trained younger, which was being more literal, more word-oriented. They're more into displays and figures, and so they need to kinda see things and see how things relate and fit together, rather than trying to guard our knowledge from looking at words. Kids are just different and so to ignore that means you're not dealing with reality. I think it's very important not to reduce the rigor, but certainly to approach things differently and grasp at anything that helps engage them and helps them become more active in the learning process. (Professor Smith)

Southwestern Public Research University Students

Formal Classroom Techniques. The introductory STEM classrooms at Southwestern Public Research University are large, lecture-based courses, often enrolling 300-500 students. A majority of the focus group participants stated that their courses consist entirely of lecture with little innovation being incorporated. Several students, however, indicated that they prefer when a professor utilizes the chalkboard or a Tablet PC in order to write out problems and demonstrate the process of arriving at the correct answer.

> I'll say kinda like I think you were saying, how like, it's better to write it out as you're going along. That's what I like better. It's like for classes like math and like, science — especially when it becomes like a process, I think it's better not to be too like, technological with it. It's better to like, have just like a simple overhead, and like, just write out, write down stuff. (Micky)

Students want professors to use more real world examples that are practical but very few have had professors that do that. Although clickers elicit mixed responses from students, a majority have used them in class while few students stated that their professors effectively utilize the clickers to gauge understanding of course material before moving on.

Out-of-Class Techniques. The large STEM courses at Southwestern Public Research University offer smaller discussion sections that are connected to the course, but few students find them helpful for increasing learning, as suggested by Meg.

> It just wasn't beneficial at all. I was like, oh my gosh, you know? And we weren't getting anything and it was the same thing. We'd get a quiz, and then we left. So it was just nothing was being re-taught, and I was like, "That's the whole point of recitation class, is to get you to understand. You know, the lecture, a little better."

Several students complained that the discussion sections lack substance and fail to increase their understanding of the material. Instead, they want the graduate student instructor to explain the material, provide extra examples, and facilitate a discussion amongst students.

Beyond the formal class setting, students reinforce learning through online homework programs and study groups. A majority of the participants have used online homework programs and most of them feel that the programs are helpful because they provide instant feedback and offer clues for correcting wrong answers. Students said that the biggest downfalls to the Web-based programs are the tedious nature of typing out math-based problems in a computer program as well as the small nuances of a computer-based program that cannot distinguish between a comma and a period.

Several students mentioned that they have found SI to be very helpful for learning in introductory STEM courses while some students prefer informal study groups with their friends. Either way, working with other students helps to reinforce the material in an environment that is less intimidating than the classroom or the professor's office hours. As reflected in this quote by

Magda, several students suggested that using the professor as a source of information is typically a last option:

> Yeah, in class I usually wait 'til someone else asks, you know? 'Cuz most people have like this same questions, where I go to like SI's or ask a friend, but I really don't contact the professor.

Context for Learning. Utilizing other students as a source of information is important for students in introductory STEM courses at Southwestern Public Research University. Despite the fact that Southwestern Public Research University is a large, public research institution, many students feel that the learning environment is collaborative and welcoming, with several students forming study groups with the people they sit next to in class and/or using the course website to recruit study group members.

> No, we have this thing like, Blackboard. Like what she said earlier, like, you can actually post in there, "Hey, I'm in the library, everybody wanna come visit me," or whatever, "we'll review together," or whatever. (Bella)

Southwestern Public Research University Faculty

Formal Classroom Techniques. Professors at Southwestern Public Research University described multiple attempts at moving beyond lecture into the use of more engaging pedagogies, including working problems on the board, bringing in PowerPoint with embedded practice problems, peer learning models, and real world application. Despite the fact that students in the focus groups expressed particular frustration with a lack of real world application, it was this final practice that was particularly salient for each professor, as they each described the importance of making STEM content “fun” and relevant to their students’ lives, as Professor Reyes described below.

> I try to make it fun…it’s application based for me, which is—I mean, I went through the traditional chemistry. Traditional chemistry’s not application based. Traditional chemistry is this is what an atom is, this is what this is…What I’ll do when we start talking about atoms, I’ll say, ‘How many of you have gone in for an MRI? What is an MRI? Why do we care what an MRI is? How does it apply to the atom? What are we

> looking at?' I immediately take it to something usually medical because most people have had grandma, grandpa, mom, dad, sister, brother, aunt, uncle in a medical environment or you've seen it on TV, and so I do that a lot.

Despite their utilization of these multiple active learning strategies, each professor expressed the same frustration, a lack of engagement on the part of their students.

> I have tried everything. I have tried the clickers. I have tried all of these methods of peer learning, POGIL, whatever you want to name it. My biggest thing is that there are just students that will not do the work. Unless I become the devil and I come with a trident and actually poke them, they just will not do it. (Professor Shephard)

Additionally, each of the three professors interviewed stressed the way in which large classes affect their ability to implement more active learning strategies in the classroom, and to move beyond lecture.

> Most of what I do is lecture, so I do the traditional lecture in the hour. I don't do any group work, partly because I have such large class sizes. You've got 100 students in the class; you break it up maybe into 20 sections, maybe? How do you control all those individual groups and make sure that they're all making progress; particularly, if it's just me as their instructor? I don't have any support. (Professor Reyes)

Out-of-class Techniques. Professors at Southwestern Public Research University described a host of out-of-class techniques aimed at enhancing students' course experience: virtual classrooms, online videos, SI, recorded lectures, blackboard, discussion boards, personal one-on-one tutoring, and online homework.

> I use a lot of things online because this is a—I think this is a digital generation. They would much rather listen to me having a recorded lecture that I put on Blackboard that's sitting through my lecture live. What I have tried doing, for example, in the last few terms is at least those topics that are really, really hard, I divide it in little chunks of material and I make some recordings in which they hear me. Maybe they don't see my face, they hear me. They see me solving problems, 'cause I have a little tablet that I can do the problem solving as well. (Professor Shephard)

These professors seemed to truly recognize and embrace the use and importance of technology outside of the classroom, and felt that these out-of-class techniques were especially critical to student learning and helping to manage their large class sizes.

Context for Learning. As is clear from both the formal classroom and out-of-class techniques, despite the fact that these professors are attempting to utilize a great many active learning strategies, three main issues seem to pervade the learning context at Southwestern Public Research University from the professors' perspective: a lack of student willingness to participate in their own learning, the effect of large class sizes, and students' lack of preparation. Here Professor Rutherford illustrates students' reluctance to utilize a program where he, himself tutors them online.

> But, I've been trying to motivate them to use a software package; which is called Illuminate that allows me to tutor them over the internet, but I don't get very much response out of 'em. As you probably find, as you go to various different colleges and universities students have a great reluctance to talk to the instructors outside of the classroom. And … uh … I find the same thing is true here. Although, I try to make myself available through this rather nice software package … can't get students to use it.

Lack of preparation was perhaps the most salient and problematic student challenge mentioned by professors. Here Professor Rutherford discussed how these poorly prepared students can get "wiped out" by introductory courses.

> Well, everybody will say the same thing; weak preparation. They come from school systems that don't prepare them adequately. At least, that's my perception and I know that everybody says it and everybody hates to say it, but it's true. The better students can hack it, but the weaker students really get wiped out by the large number of ideas in a single course that they're exposed to.

These findings make it clear that the professors describe employing a great deal more innovation and active learning pedagogies both in and out of the classroom than the students are experiencing. Thus despite the fact that a good deal of innovation is occurring, it does not seem to be standard practice, and instead relies upon the efforts of individual professors.

When looking across institutional types it becomes clear that the large public research universities are distinct from the other institutions in our sample in several ways. The large class sizes limit professors' ability to implement more innovative and active learning based classroom techniques, as does the heavy emphasis on research over teaching. However at least one of these institutions recognized and compensated for this heavy dependence on lecture through a system of highly structured, organized, and effective out-of-class techniques, including recitations, tutoring, review sessions, and additional use of technological innovation. Additionally, the predominance of highly driven, career oriented students makes for a more competitive atmosphere from the faculty perspective, although students did not report this sense of competition. The smaller institutions were able to keep their class sizes more manageable and their focus primarily on teaching, and in this way readily employed a host of active learning techniques and innovation both in and out of the classroom. The two MSIs in our sample suffered from a similar plight, that of underprepared students who professors felt were ill equipped to handle college level courses. Yet, despite all of these institutional level differences, both individuals and small cadres of dedicated professors interested in truly engaging students in active learning continue to push introductory STEM courses beyond lecture. In the following section we discuss ways in which these more student centered teaching/learning approaches can be more widely adapted and made a part of institutional culture.

Discussion

In 2008, the National Research Council (NRC) hosted two workshops that focused on promising practices for teaching in the undergraduate STEM classroom (NRC, 2011). Although the abundance of literature on innovative practices in STEM education suggests that we have come a long way since the 1990's when the NRC, National Science Foundation (NSF), and others (e.g., Gainen, 1995; Seymour & Hewitt, 1997; Tobias, 1990) originally called for changes in pedagogical practices, there is still much work to be done to assess the broader impact of these innovative techniques (NRC, 2011). This study is one attempt to compare convergent and divergent themes in innovative techniques across multiple institutions.

Three main themes emerged from the data including the use of formal classroom techniques (by faculty), the enactment of both formal and informal out-of-class techniques (by both faculty and students), and the influence of the context for learning. Although Froyd (2008) suggests there are eight strategies for effective STEM undergraduate education, we loosely found support for four (organize students in small groups, provide students feedback through systematic formative assessment, design in-class activities to actively engage students, faculty-initiated approaches to student-faculty interactions) while discovering additional aspects that should be considered including the use of in- and out-of-class technology and the incorporation of real world and hands on applications. The findings of this study also suggest that we focus on place and context for learning in addition to actual techniques, and most importantly, we need to expand our understanding of how some faculty overcome the constraints of pre-college preparation and large class sizes.

Students across several institutions suggested that they learn best when professors merge real world applications into content-based lectures. Although many of them said that real world examples make the lecture more interesting and engaging, they also talked about the way that these examples help them to recall the information during exams and help them to move beyond abstract concepts and into real world applications for career exploration. Faculty agreed with the students, often giving concrete examples of various ways that they have tried to make the lecture fun, relevant, and reflexive. Although not suggested by Froyd (2008), there are a number research scientists who have argued that curriculum changes in STEM should focus on real-world issues that engage students, help them to learn, and peak their interest in the subject (e.g., Duffy, Godduhn, Fabbri, Muelken, Nicholas-Figueroa, & Middlecamp, 2011; Middlecamp, 2008).

Within the classroom, professors have also incorporated technology as a way to increase learning. The use of student response systems ("clickers") seem ubiquitous, with a majority of students at all eight institutions reporting that they have used them, but responses to these systems are mixed. As suggested by Froyd (2008), these systems are effective for providing students with immediate feedback for assessing and improving their learning; however, our data suggest that students across institutions are not realizing this benefit. Perhaps the response systems are effective for engaging the most proactive students (Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2011), but they may not be the most effective tool for all students at all institutions. This may be due in part to variation in the ways instructors use them, some of which are tied with point-systems. These findings support previous research that has been mixed in regard to the usefulness of clickers in the classroom (e.g., Crossgrove & Curran, 2008; Nagy-Shadman & Desrochers, 2008; Preszler et al., 2007).

Although several faculty members stated that they have tried clickers in their large lecture courses, other in-class educational enhancement techniques emerged as the most effective for faculty in our sample including ELMO and tablet PCs (Dyno). The research on these two techniques is not extensive but Professor Norris suggested that tablet PCs may in fact enhance communication with students, or what Froyd (2008) calls faculty-initiated approaches to student-faculty interaction. Among our student sample, there were less examples of the use and effectiveness of these in-class techniques, aside from a few at Southeastern Public Master's College and Southwestern Public Research University. Perhaps these techniques have not been widely adopted in STEM introductory classrooms yet.

Across all eight institutions, we found that despite the fact that some professors are employing innovative techniques within the formal classroom setting, it does not seem to be standard practice. The innovators of these in-class techniques have tried to design in-class activities that actively engage students (Froyd, 2008) using techniques such as group projects, student presentations, reflective writing, case studies, animations, team-based projects, think-pair-share, peer instructional models, and visualizations, to name a few. As evidenced by the few number of students who mentioned any of the above techniques (across all institutions), these strategies are clearly not universal.

Outside of the formal classroom, a number of techniques and strategies emerged as helpful and relevant for learning. A majority of out-of-class techniques, however, are strongly tied to the formal class structure. The use of SI, workshops, and formal study groups were by far the most cited examples of out-of-class techniques that help students to learn the abundance of material required in introductory STEM courses. Although these techniques are called different names at different institutions, they are all formalized resources supported by the institution. As suggested by Froyd (2008), organizing students in small groups is a highly cited way of increasing learning within STEM classrooms. Out-of-class strategies for engaging students in small groups, including SI and workshops, are not mentioned by Froyd, despite the number of studies that have indicated their ability to increase learning and retention (e.g., Bowles et al., 2008; Ramirez, 1997; Rath et al., 2008; Villarejo et al., 2008). During the workshops hosted by NRC in 2008, leading scientific educational researchers also overlooked these out-of-class techniques as promising strategies. The data in this study, however, provide strong evidence for the use and effectiveness of institutionally supported study groups (including SI and workshops).

Out-of-class technology, including the use of Web-based homework and podcasts, were mentioned by students and faculty as potential tools to enhance classroom learning. The podcasts, however, are not nearly as prominent as the Web-based homework, with students at Western Public Research University and faculty and Midwestern Public Research University being the main supporters of the podcast technology. Similar to the in-class clickers, responses to the Web-based homework were mixed. In comparison to existing literature, our data suggest that Web-based homework may be best for increasing time on task (Allain & Williams, 2006) and engagement (Gasiewski et al., 2011), but may not actually increase learning (Bonham et al., 2003).

In addition to in-class pedagogical changes and out-of-class strategies that we found as most effective for teaching and learning in introductory STEM courses, we found that the context for learning must be considered. A majority of the research on the introductory STEM environment has been focused on the strategies with little to no consideration for the environment. This may be related to the fact that a majority of studies have been conducted at a single site by the research scientists teaching the course. Our findings, therefore, highlight an important consideration for future research that is focused on teaching and learning in introductory STEM courses. Although previous research suggests that there is a competitive environment within STEM, our data suggest that there may be more of a collaborative environment than previously suggested. Two institutions (Southwestern Private Research University and Southeastern Private Master's College) stood out as far as having an intensely competitive environment, which was mostly attributed to the pre-medical focus at these institutions. The spirit of collaboration, however, strongly outweighed the competitive culture that is often expected within the hard sciences. As suggested by some students, the competitive environment may actually force students to work together in order to succeed. This is a phenomenon that should be examined further in future research.

Implications for Research and Practice

This study highlighted distinct environments and variation in both students' and faculty experiences in STEM classrooms. There is evidence that some innovation is occurring but typically, one instructor at a time. Collective efforts are lacking that might change the norms and expectations for both students and faculty. A variety of foundations are poised to support innovation in STEM, including NSF and the Howard Hughes Medical Institute (HHMI), but good ideas have to be offered that also have promise of institutionalization. We documented that outside of classroom activities have increased the time that students spend on science, which is a positive sign that more attention to learning is occurring regarding the content that is delivered in class. However, "whatever makes it stick" for different students should be more systematic and more widely available. In some cases, introductory labs are adopting authentic research projects to ensure more involvement of students in the scientific knowledge production process (Science Education Alliance). The latter is a large scale, collective effort that produced a community of faculty committed to innovation. This effort required training of faculty and teaching assistants and cross-institutional sharing of practices to link classrooms with 'big science' projects of national importance. It is likely that institutionally based-efforts can also be successful in improving student learning and teaching capacity that do not have to be divorced from research intensive goals. Deans and department chairs are critical in ensuring broader adoption of innovations that ensure more college graduates are scientifically literate and/or foster the scientific talent that will bring about the next innovation in science. Although this paper highlights the progress that is clearly being made, we have a long way to go to reach the place where, as suggested by McWilliam et al. (2008), innovative pedagogies will allow future scientists to be competitive within an ever-changing STEM environment.

References

Alberts, B. (2005). A wakeup call for science faculty. *Cell, 123*, 739-741. doi:10.1016/j.cell.2005.11.014

Allain, R. & Williams, T. (2006). The effectiveness of online homework in an introductory science class. *Journal of College Science Teaching, 35*(6), 28-30.

Bonham, S.W., Deardorff, D.L., & Beichner, R.J. (2003). Comparison of student performance using Web and paper-based homework in college-level physics. *Journal of Research in Science Teaching, 40*(10), 1050-1071. doi:10.1002/tea10120

Bowles, T. J., McCoy, A. C., & Bates, S. C. (2008). The effect of supplemental instruction on timely graduation. *College Student Journal, 42*(30), 853-859.

Brock, R. (2005). Lectures on the go. *Chronicle of Higher Education, 52*(10), A39-A42.

Caldwell, J. E. (2007). Clickers in the large classroom: Current research and best-practice tips. *Life Sciences Education, 6,* 9-20.

Campbell, G. (2005). There's something in the air: Podcasting in education. *Educause Review, 40,* 32-47.

Carle, A. C., Jaffee, D., & Miller, D. (2009). Engaging college science students and changing academic achievement with technology: A quasi-experimental preliminary investigation. *Computers & Education, 52*, 376-380. doi: 10.1016/j.compedu.2008.09.005

Chickering, A.W. & Gamson, Z.F. (1987). Seven principles for good practice in undergraduate education. *AAHE Bulletin, 39*(7), 3-7.

Creswell, J. (2007). *Qualitative inquiry & research design: Choosing among five approaches* (2 ed.). Thousand Oaks, CA: Sage Publications, Inc.

Crossgrove, K. & Curran, K. L. (2008). Using clickers in nonmajors- and majors-level biology courses: Student opinion, learning, and long-term retention of course material. *Life Sciences Education, 7,* 145-154.

Freeman, S., O'Connor, E., Parks, J.W., Cunningham, M., Hurley, D., Haak, D., Dirks, C., & Wenderoth, M. P. (2007). Prescribed active learning increases performance in introductory biology. *Life Science Education, 6,* 132-139. doi:10.1187/cbe.06-09-0194

Froyd, J. E. (2008). White paper on promising practices in Undergraduate STEM education. Retrieved from http://www.physics.emory.edu/Faculty/weeks/journal/froyd-na08.pdf

DeAngelo, L., Hurtado, S., Pryor, J.H., Kelly, K.R., Santos, J.L., Korn, W.S. (2009). *The American college teacher: National norms for the 2007-2007 HERI faculty survey*. Los

Angeles, CA: Higher Education Research Institute, University of California, Los Angeles.

DeHaan, R.L. (2005). The impending revolution in undergraduate science education. *Journal of Science Education and Technology, 14(2)*, 253-269. doi:10.1007/s10956-005-4425-3

Duffy, L. K., Godduhn, A., Fabbri, C. E., Muelken, M., Nicholas-Figueroa, L., & Middlecamp, C. H. (2011). Engaging students in science courses: Lessons of change from the Arctic. *Interchange, 42*(2), 105-136. doi:10.1007/s10780-011-9151-6

Gainen, J. (1995). Barriers to success in quantitative gatekeeper courses. In J. Gainen & E. W. Willemsen, (Eds.), *Fostering student success in quantitative gateway courses.* New Directions for Teaching and Learning, no. 61. San Francisco, CA: Jossey-Bass.

Gasiewski, J. W., Eagan, M. K., Garcia, G. A., Hurtado, S. & Chang, H. J. (2011). From Gatekeeping to Engagement: A Multicontextual, Mixed Method Study of Student Academic Engagement in Introductory STEM Courses. Manuscript under review.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M., & Wood, W.B. (2004). Scientific teaching. *Science, 304*, 5670, 521–522.

Higher Education Research Institute (2010). Degrees of success: Bachelor's degree completion rates among initial STEM majors. *HERI Research Brief*. Los Angeles, CA: University of California, Los Angeles.

Kemmis, S. (2006) Participatory action research and the public sphere. *Educational Action Research*, *14*(4), 459-476.

Knight, J.K. & Wood, W.B. (2005). Teaching more by lecturing less. *Cell Biology Education, 4,* 298-310.

Leitch, R., Gardner, J., Mitchell, S., Lundy, L., Odena, O., Galanouli, D. & Clough, P. (2007). Consulting pupils in assessment for learning classrooms: The twists and turns of working with students as co-researchers. *Educational Action Research 15*(3), 459-478.

Marrs, K.A. & Novak, G. (2004). Just-in-Time Teaching in biology: Creating an active learner classroom using the Internet. *Cell Biology Education*, *3*, 49-61. doi:10.1178/cbe.03-11-0022

Maxwell, J. (2005). *Qualitative research design: An interactive approach*. Thousand Oaks, CA: Sage Publications.

McDaniel, C.N., Lister, B.C., Hanna, M.H., & Roy, H. (2007). Increased learning observed in redesigned introductory biology course that employed Web-enhanced, interactive pedagogy. *Life Sciences Education, 6*, 243-249.

McFarlin, B.K. (2008). Hybrid lecture-online format increases student grades in an undergraduate exercise physiology course at a large urban university. *Advances in Physiology Education, 32,* 86-91.

McWilliam, E., Poronnik, P., & Taylor, P.G. (2008). Re-designing science pedagogy: Reversing the flight from science. *Journal of Science Education and Technology, 17*(3), 226-235. doi:10.1007/s10956-008-9092-8

Merriam, S. (1998). *Qualitative research and case study applications in education*. San Francisco, CA: Jossey-Bass Publishers.

Middlecamp, C. (2008). Chemistry in context: Goals, evidence and gaps. Presented to the Board of Science Education, National Academy of Science, Washington, DC. Retrieved from http://www7.nationalacademies.org/bose/PP_Middlecamp_WhitePaper.pdf

Miles, M., & Huberman, A. (1994). *Qualitative data analysis: An expanded sourcebook* (2 ed.). Thousand Oaks, CA: SAGE publications.

Nagy-Shadman, E. & Desrochers, C. (2008). Student response technology: Empirically grounded or just a gimmick? *International Journal of Science Education, 30*(15), 2023-2066.

National Research Council. (2011). *Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics Education: Summary of Two Workshops*. Natalie Nielsen, Rapporteur. Planning Committee on Evidence on Selected Innovations in Undergraduate STEM Education. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Niemi, R., Heikkinen, H., & Kannas, K. (2010). Polyphony in the classroom: reporting narrative action research reflexively. *Educational Action Research, 18(*2), 137 – 149.

O'Brien, N. & Moules, T. (2007) So round the spiral again: A reflective participatory research project with children and young people. *Educational Action Research, 15*(3), 358-402.

Patton, M. (2002). *Qualitative research and evaluation methods, 3rd ed.* Thousand Oaks, CA: Sage Publications.

Peters, A.W. (2005). Teaching biochemistry at a minority-serving institution: An evaluation of the role of collaborative learning as a tool for science mastery. *Journal of Chemical Education, 82*(4), 571-574).

Preszler, R.W., Dawe, A., Shuster, C.B., & Shuster, M. (2007). Assessment of the effects of student response systems on student learning and attitudes over a broad range of biology courses. *Life Sciences Education, 6*, 29-41. doi:10.1187/cbe.06-09-0190

Ramirez, G. M. (1997). Supplemental instruction: The long-term impact. *Journal of*

Developmental Education, 21(1), 2-9.

Rath, K. A., Peterfreund, A. R., Xenos, S. P., Bayliss, F., & Carnal, N. (2007). Supplemental Instruction in introductory biology I: Enhancing the performance and retention of underrepresented minority students. *CBE Life Sciences Education, 6,* 203-216. doi: 10.1187/cbe.06-10-0198

Schlairet, M. C. (2010). Efficacy of podcasting: Use in undergraduate and graduate programs in a College of Nursing. *Journal of Nursing Education, 49*(9), 529-533.

Seymour, E., & Hewitt, N.M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder, CO: Westview Press.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research, 69*(1), 21-51.

Stake, R. (2006). *Multiple Case Study Analysis*. New York: Guilford.

Tobias, S. (1990). Stemming the science shortfall at college. In S. Tobias (Ed.), *They're not dumb, they're different.* Tucson, AZ: Research Corporation.

Villarejo, M., Barlow, A. E. L., Kogan, D., Veazey, B. D., & Sweeney, J. K. (2008). Encouraging minority undergraduates to chose science careers: Career path survey results. *CBE Life Sciences Education, 7*, 394-409. doi: 10.1187/cbe.08-04-0018

Zeilik, M. & Morris, V J. (2004). The impact of cooperative quizzes in a large introductory astronomy course for non-science majors. *Astronomy Education Review, 3*(1), 51-61.

Zerr, R. (2007). A quantitative and qualitative analysis of the effectiveness of online homework in first-semester calculus. *Journal of Computers in Mathematics and Science Teaching, 26*(1), 55-73.

Appendix A
Chart of Institutional Characteristics

Institution	Full Time Enrollment	Funding	Predominant Racial Designation	Carnegie Classification	Region	SAT Selectivity Measure 75% percentile	Annual Research Dollars	Sample Size
Southwestern Private Research University	> 10,000	Private	Predominantly White	Research Universities (high research activity)	Southwest	1290	<75 million	52 students
Southeastern Private Master's College	< 10,000	Private	Predominantly White	Master's Colleges and Universities (smaller programs)	Southeast	1310	<5 million	18 Students
Midwestern Public Research University	> 25,000	Public	Predominantly White	Research Universities (very high research activity)	Midwest	1430	<1 billion	37 Students
Southeastern Public Master's College	< 10,000	Public	Historically Black	Master's Colleges and Universities (larger programs)	Southeast	930	<5 million	25 Students
Western Private Master's College	< 5,000	Private	Predominantly White	Master's Colleges and Universities (larger programs)	West	1290	<5 million	39 Students
Northeastern Private Master's College	> 10,000	Private	Predominantly White	Master's Colleges and Universities (larger programs)	Northeast	1310	<75 million	32 Students
Western Public Research University	> 25,000	Public	Predominantly White	Research Universities (very high research activity)	West	1400	<1 billion	20 Students
Southwestern Public Research University	> 25,000	Public	Hispanic Serving	Research Universities (high research activity)	Southwest	1140	<75 million	16 Students