Factors Underlying the Adoption and Adaption of a University Physics Reform over Three Generations of Implementation

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Abstract

SCALE-UP (Student-Centered Active Learning Environment with Upside-Down Pedagogies) (Beichner et al., 2007) is a reformed pedagogy and classroom design originally developed for large enrollment university physics courses at North Carolina State University. It is currently being used at over 250 institutions worldwide and has since expanded into other content areas. This exploratory case study examines how classroom, departmental, institutional and cultural factors have caused the reform to evolve over three generations of implementation from its development site to a well-known American implementation and a site in Singapore.

A mixed methods study using interviews and class observations reveal the implementation process follows an iterative version of Rogers' (2003) "Innovation in Organizations" model, as institutions re-invent and refine the reform to adapt to their institution. The findings suggest some changes ensure the survival of the reform, for example, adjusting instruction to fit available resources or student learning styles. However, many modifications shift pedagogy toward traditional instruction, potentially decreasing the reform's intended benefits. Awareness of this tendency could help researchers, curriculum and professional development developers and future implementers better support sustainable and effective use of research-based pedagogies.

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Key words: studio learning, SCALE-UP, diffusion of innovations, active learning, TEAL

Introduction

Efforts to attract and support undergraduates in their pursuit of STEM careers have led to large-scale research and development efforts to improve introductory courses. From 1950 to 2005, the Directorate for Education and Human Resources of the National Science Foundation (NSF) has contributed over $22 billion to this cause (NSF, 2005). Multiple studies document improved learning from student-centered, interactive techniques but many undergraduate science courses still primarily rely on lecture-based, traditional instruction suggesting that reformed pedagogies fail to create a widespread and permanent transformation (McCray, DeHaan & Schuck, 2003; Redish, 2003). Researchers often assume that developing reformed pedagogies and publishing its effectiveness is enough to promote adoption but this intuitive "show them and they will adopt" model is inadequate (Henderson & Dancy, 2009a; Henderson & Dancy, 2009b). Following the calls of Fairweather (2008) and Seymour (2011), a more research-based model of change is needed to describe widespread and effective pedagogical transformations.

In addition to existing literature lacking an adequate, overarching framework, very few studies examine secondary implementers who use research-based strategies developed elsewhere. As the most common type of implementation, secondary users face additional challenges worthy of investigation. Secondary sites often do not have access to the grant funding, a project team and other resources that contribute to success at the original development site. Most published studies of secondary sites are products of grants with dissemination funding and thus have the unusual "best case scenario" of having financial support and direct developer involvement (e.g. Saul & Redish, 1997; Wittman, 2002), which most ordinary implementations may not have. Furthermore, the transfer is complicated by differences in student population, instructor personality and institutional characteristics, (Pollock & Finkelstein, 2007; Saul & Redish, 1997; Sharma et al., 2010) threatening the effectiveness of the implemented reform.

Consequently, many instructors make significant modifications, often leading to decreases in learning outcomes (Dancy & Henderson, 2010; Henderson, 2005, 2008; Henderson & Dancy, 2009). Most of these modifications are not documented or tracked so reforms that fail to live up to faculty/institutional expectations can cause frustration and confusion. For example, a ten-year study of Interactive Lecture Demonstrations implemented at a secondary site found actual learning gains were "nowhere near" those claimed by developers (Sharma, et al., 2010). Without investigating what modifications have been made during implementation, "it may be difficult to interpret learning outcomes and to relate these to possible determinants" (Fullan & Pomfret, 1977, p. 338).

Current research and curriculum development efforts in STEM education may have a reduced impact without a realistic model that describes how reforms spread, evolve and achieve successful outcomes. Although this study does not attempt to measure outcomes, it provides detailed qualitative insights about what classroom, departmental, institutional and cultural factors impact the change effort, investigating how and why implementers make modifications. This exploratory case study is part of a larger, more quantitative study that examines the initiation and current status of SCALE-UP (Student-Centered Active Learning Environment with Upside-down Pedagogies) (Beichner, Saul, Abbott, Morse, Deardorff, Allain & Risley, 2007; Beichner, 2008) implementations worldwide. This case study closely examines how the reform evolves as it moves from its development site at North Carolina State University (NCSU), to one of the most well-known implementations at Massachusetts Institute of Technology (MIT), to an international site at Singapore University of Technology and Design (SUTD). Characterizing how the innovative pedagogy adapts to different environments will help lead to research-based recommendations to support and sustain educational change, especially in college level science courses.

Literature Review

What is SCALE-UP and why study it?

Dr. Robert Beichner developed SCALE-UP for large enrollment university physics courses at North Carolina State University in 1997. This reformed pedagogy and classroom environment has successfully crossed disciplines and continents, and is currently used at over 250 sites worldwide (NCSU PER&D, 2011). Results from this study help develop generalized knowledge about the successful spread of research-based strategies. Users of SCALE-UP may be particularly interested in the findings to guide their own use of the reform.

SCALE-UP radically changes the instructional methodology and course structure by integrating lab-lecture-recitation and redesigning the classroom to a studio environment. Special tables, whiteboards on walls and technology with projection capabilities facilitates collaboration and sharing of student work. A room without an obvious "front" encourages instructors to circulate the classroom and engage teams of students in Socratic dialogues, real-world problem solving and technology-rich activities, while minimizing lecture. Radical reforms like SCALE-UP often require departmental buy-in, but typically lead to greater learning outcomes (Redish, 2003). SCALE-UP has been shown to improve student problem solving abilities, conceptual understanding, attitudes toward science, retention in introductory courses (Beichner, et al., 2007; Beichner, et al., 2000) and performance in later courses (Dori, Hult, Breslow & Belcher, 2007). Thus, aiding the dissemination of an effective reform like SCALE-UP can further spread these documented benefits.

Implementing Active Learning Classrooms in Asia and the United States

Examining the implementation of the reform in Singapore is particularly interesting and important since more Asian institutions are moving toward student-centered instruction. For example, in Southeast Asia, an interactive communication technology initiative was developed to increase the use of technology to engage students with formative feedback and interactive instruction (Southeast Asian Ministers of Education Organization, 2010).

Existing literature on active learning in Asia is generally restricted to SCALE-UP style implementation efforts in Taiwan but suggest that cultural traditions may complicate the use of innovative pedagogies. Chang (2005) indicates students in Taiwan usually passively receive knowledge delivered by their instructor with traditional lectures. Subsequently, some students resist unfamiliar, active, constructivist instruction. Technology Enriched Active Learning (TEAL) was implemented at National Chung Cheng University (CCU) in 2004, also in collaboration with MIT (who pioneered this new acronym for their SCALE-UP adaption), so the classroom was "highly similar… both hardware-wise and software-wise" (Shieh, Chang & Liu, 2011, p. 1083). Even though TEAL classes were equipped with technological resources to promote interaction, class observations revealed, "the learning setting did not seem to have effectively assisted them to learn in an active manner. During the classes, students spend most of their time taking notes" (Shieh, Chang & Tang, 2010, p. 411).

Not surprisingly, the study found low learning gains in TEAL sections, compared to what was deemed typical for interactive courses by Hake (1998). Researchers attributed low gains partially to "instructors' lack of proficiency in and unfamiliarity with innovative teaching skills, being obliged to complete the uniform, pre-determined, course materials" (Shieh et al., 2010, p. 411) thus not having enough time (and training) to appropriately engage students with passive learning habits.

Lower than anticipated learning gains are not restricted to Taiwan; studies reveal student learning at US institutions was also low until faculty aligned their pedagogy to the redesigned collaborative learning environment. Similar to CCU, studies of studio classrooms at Rensselaer

Polytechnic Institute (Cummings, Thornton & Kuhl, 1999) and Colorado School of Mines (CSM) did not find immediate or simultaneous shifts in performance (Kohl & Kuo, 2012) as a result of only renovating the space. However, when CSM redesigned the curriculum to match the goals of the classroom, they found improvements on exam tasks and problem solving (Kohl & Kuo, 2012). Successful change in Asia may require more professional development than in the US since active learning is less pervasive in Asia, thus faculty are even less familiar with these methods, but the US studies show that progress is possible even if initial learning gains are low.

Even though CCU encountered some difficulties adjusting TEAL practices to fit an interactive classroom design and initial learning gains were lower than expected, these classrooms are becoming more widespread. Shieh, Chang & Tang (2010) found students generally showed positive attitudes toward TEAL and outperformed their traditional counterparts. These benefits inspired Taiwan's Ministry of Education to launch TEAL classrooms in up to 50 high schools and Shieh (2012) found this led to a higher interest in attending class, increased participation in extracurricular science activities and positive changes in the teachers' abilities to promote conceptual understanding.

In summary, existing research indicates that traditionally didactic teaching styles and passive learning styles can complicate the implementation of active learning strategies in Asia, especially if the instructional strategy does not change to compliment the studio-style classroom. However, innovative instructional strategies are becoming more prevalent in Asian settings so investigating the use of TEAL in Singapore will add important insights to how to use innovative instruction in countries where traditional teaching dominates.

Theoretical framework: Diffusion of Innovations

This case study can be viewed through the theoretical framework of adoption of innovations. Several theoretical models for the diffusion of innovations exist (summarized in Grunwald, 2004), but this study will use the most frequently cited model, Rogers' (2003) five-step innovation-decision model. Rogers defines this process as how a decision-maker "passes from gaining initial knowledge of an innovation, to forming an attitude toward the innovation, to making a decision to adopt or reject it, to implementing the new idea, and to confirming this decision" (Rogers 2003, p. 168). However, since the adoption of SCALE-UP involves radical restructuring of both the physical classroom and the schedule (to integrate the lab-lecture-recitation sections of the course), the decision to adopt typically occurs at the departmental level. Thus, this study will use Rogers' innovation process of organizations model shown in Figure 1, under the assumption that successful initiation and execution of reform relies more heavily on the coordination of efforts at the higher departmental level.

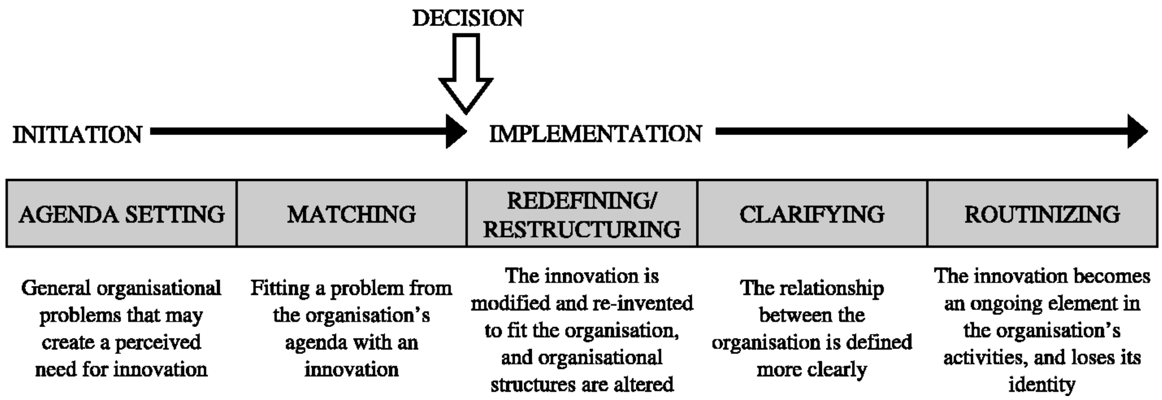

Figure 1: Implementation in organizations (Rogers, 2003, p. 421)

The *initiation phase* leads to the decision to adopt and is subdivided into an agenda-setting and matching phase. During **agenda setting**, the organization defines a problem and creates a perceived need for the innovation. During **matching**, the organization pairs their agenda with the innovation to establish how well they coincide.

The *implementation phase* incorporates all events, decisions and actions involved with putting the innovation into use, divided into three sub-steps. The **redefining-restructuring** stage captures the mutual adaptation of the innovation and the organization, as both are re-invented to accommodate the organization's needs and existing structure. "Innovations not only adapt to existing organizational and industrial arrangements but also transform the structure and practice of these environments" (Van de Ven, 1986, p. 591). **Clarifying** helps the meaning of the new idea become clearer to its members as they figure out how it works, what it does, and who in the organization will be affected as it spreads. **Routinization** occurs when the innovation is assimilated to an extent that it loses its separate identity. The sustainability (continued use) of the reform is increased when adopters re-invent it to fit their local surroundings because "they begin to regard it as their own, and are more likely to continue it over time, even when the initial special resources are withdrawn or diminish" (Rogers, 2003, p. 429).

This case study examines the diffusion and implementation of SCALE-UP from its development site at NCSU through two transitions (to MIT and SUTD) in light of this framework, while specifying more specific departmental, institutional and cultural factors that can propel or impede progress toward routinization.

Methods

The goal of this study is to characterize implementations to develop a detailed understanding of the implementation process at each site. Insights gained from this case study aim to streamline the implementation process for future adopters by identifying common challenges and potential solutions. Overall characteristics describing the three sites examined in this study are shown below.

NCSU	**MIT**	**SUTD**
Est. 1887	Est. 1861	Est. 2009
33,819 students	10,284 students	~600 students

Public research univ.	Private research univ.	Autonomous national univ.
Full-time, more-selective 4-year institutions		
Balanced arts & science curriculum		Eng., tech. and design focus
High graduate coexistence		Undergrad. (Graduate programs begin in 2014)
SCALE-UP since 1997	TEAL since 2003	Cohorts since April 2012

Figure 2: A comparison of major characteristics of the three universities under consideration

Research questions

RQ1: How are secondary implementations of the SCALE-UP reform initiated?

RQ2: How do sites factors redefine and restructure a reform to fit their unique setting? What classroom, departmental, institutional and cultural factors motivate modifications?

RQ3: How do sites factors clarify and routinize the use of a reform for their unique setting? Why?

RQ4: How does the final implementation compare to the original reform?

Data collection

This study took a mixed-methods approach to data collection at all institutions. Semi-structured interviews with faculty and administrators and a review of site documents explored the initiation stages of the reform. To characterize the implementation stages, these data sources were supplemented by classroom observations with informal student interviews and an appraisal of course documents (syllabi, assessment, clicker questions, etc.).

Interviews. The researcher conducted semi-structured, hour-long interviews of faculty and administrators involved in the implementation of the reform at NCSU (three people), MIT (two people) and SUTD (four people). Interviews were audio-recorded, transcribed, segmented into topic-oriented chunks and analyzed using a systematic coding procedure known as the *constant comparison* method (Corbin & Strauss, 2008). As defined by Strauss and Corbin (2008), the process involved three primary stages - *open coding*, *axial coding*, and *selective coding.* During open coding, the researcher developed a preliminary coding schema and labeled segments with broad codes of factors that influence the implementation process based on educational reform literature (Henderson, Beach & Finkelstein, 2011; Rogers, 2003) and emerging ideas in the transcripts. The next stage, known as axial coding, involved assigning and condensing the original assemblage of codes into progressively larger codes, which grouped codes as those related to classroom, departmental, institutional and cultural factors. The final stage, selective coding, involved making further connections with the axial code structures, ultimately resulting in broader thematic findings. During this stage, relevant statements were tagged with the implementation stage (agenda setting, matching, redefining-restructuring, clarifying, routinizing) and labeled as "motive" and "restrictive" forces if factors were explicitly recognized as helpful or harmful, respectively. These additional labels helped make informed generalizations about when and how contextual factors impact the implementation process. Throughout this process, codes that were no longer applicable or discounted by other evidence were discarded.

After assigning codes, results were sorted by variables of interest (stages of the implementation process, motive versus restrictive forces, by institution) to compare the frequency of certain codes to support research claims. Sorting segments quantitatively allowed the data to speak for itself and helped minimize any initial biases of the researchers.

Classroom observations. Time limitations at geographically distant data collection sites allowed for approximately one week of classroom observations at each site, with the primary researcher present at all three. The researcher worked as a teaching assistant during a prior semester of SCALE-UP at NCSU, and thus is very familiar with how SCALE-UP runs at the development site. Since observations were limited, class observations supplement preliminary conclusions based on more easily validated data sources including faculty interviews, course documents and existing literature. Prior to conducting classroom visits, the researcher collaborated with another researcher to establish an observational protocol, with note taking and activity logs. The classes were videotaped to see if enough information could be recorded to accurately capture remote observations but the quality of the video (despite multiple cameras) did not depict the instructor-student interactions in enough detail to be useful as a data source. Ultimately, the two researchers could reach consistent agreement on activity logs with time stamps so that was the primary data retained from classroom observations.

NCSU only had one section of SCALE-UP for the first semester mechanics introductory physics course for engineers so only one instructor was observed, during the last week of the semester. At MIT, three sections with different instructors were observed mid-semester in their electricity and magnetism introductory physics course, a core requirement for all students (except for physics majors and other students who elect to take the more rigorous version). At SUTD, class observations lasted more than a week, primarily following one cohort in their required mechanics course, but were supplemented with more sporadic observations of two other instructional teams.

During classroom observations, activities were logged with time stamps to determine the percentage of class time spent in various types of activities. Ultimately, activities were assigned one of five categories. These categories were developed from consulting SCALE-UP literature about key activities associated with desired outcomes (improved conceptual understanding, problem solving, etc.) and making sure the categories encompassed observed classroom activities.

Activity	Description
Instructor lectures	Unidirectional dissemination of content/information from the instructor to the students. Conducting a demonstration or showing a video falls under this category if instructor controls the flow of information and does not use these tools to initiate a conceptual discussion. Reviewing information from past lessons and organizational information about upcoming assessments or activities also falls under this category.
Concept questions	The instructor poses a question to the students, either by asking the class and expecting students to volunteer answers or polls students through personal response systems, allowing for small group discussion. This category includes asking the question, class discussions regarding the

	question and explaining the answer.
Problem solving	Students work alone or in small groups on solving quantitative problems or a detailed analysis of a physical situation, using physics formulas or principals. Asking/setting up the problem, students working on the problem, instructors giving hints or feedback during this process all fall under this category.
Hands-on activities	Students are engaged in activities that require more than just a pencil and paper (or a whiteboard and a marker), including using computer simulations, making measurements and doing mini labs. Follow-up discussion to the activity falls under this category.
Student Presentations	Unidirectional dissemination of content from students to the instructor or to other students. Students share their solutions and/or work with the whole class as the focus of the current class activity. Thus instances when students explain concepts to team members in small groups do not fall under this category or provide short responses to questions directed to the class do not fall under this category. However, supplemental questions asked by instructors to student groups to encourage elaboration or further clarification are coded as presentation.

Table 1: Description of coding scheme for class activities

While engaged in the primary task of logging activities, the researcher took notes on specific behaviors of the instructor and students as well as overall levels of engagement. Triangulating notes with other data sources ensured that self-described teaching practices reported by interviewees corresponded with observed implementations.

Information from interviews and observations were supplemented by an analysis of relevant literature and classroom documents. Syllabi, assessment and problem sets helped clarify classroom expectations and student evaluation. Press releases, brochures for perspective students and research publications were also analyzed for information about each institution's mission, establishment and target student population.

Credibility. Efforts were made to authentically portray the adoption and adaption process for this reform. Multiple sources of evidence are used and results were based on all the collected evidence (Yin, 2009). In addition to establishing inter-rater reliability with the collaboration of another researcher for the analysis of the interviews, multiple data sources were triangulated to verify thematic findings. To enhance the validity of the findings, the results were sent to all interviewees to review and verify.

Results and Discussion

The results of this study are presented by research question and thus are organized by the stage of the implementation process. The results come from analysis of interviews, class observations and an analysis of relevant documents.

Research Question 1: Initiation (Agenda-setting and matching)
Results 1

The idea for SCALE-UP originated when Beichner team-taught an integrated, interdisciplinary physics-engineering-chemistry course that used a mix of research-based pedagogies to teach 36 students. He states that teaching this course was “probably the most interesting, rewarding teaching I’ve ever done” but “it ended up being so much work that we realized that no one else would be crazy enough to try it”. After witnessing the effectiveness of interactive instruction, Beichner did not want to return to lecturing. He aimed to “scale up” research-based teaching methods designed for small classes so his introductory physics courses of 100 students could benefit. Around the same time, Beichner’s colleague was developing WebAssign (Beichner et al., 2008), an on-line problem delivery system that enabled the management of such a large class. Electronic grading helped hold students accountable and give them feedback to ensure they completed pre-class reading quizzes, practice problems and in-class assignments, while greatly reducing hand grading.

Dr. John Belcher at Massachusetts Institute of Technology (MIT) met Beichner and heard about SCALE-UP while collaborating on another grant. Low attendance rates (sometimes down to 40%) and high failure rates (up to 15%) in physics frustrated Belcher and pressured the MIT physics department to improve introductory courses. Backed with departmental support, when funding was secured, Belcher adapted the SCALE-UP reform for use in the second semester electromagnetism course in Fall 2010. He added two- and three-dimensional visualizations that illustrate electromagnetic fields to help students “see” what they might have difficulty grasping intuitively or mathematically and renamed the reform TEAL (“Technology Enriched Active Leaning”). Now, every MIT student takes the two-semester introductory physics sequence in these reformed classrooms.

MIT collaborated in the foundation of Singapore University of Technology and Design (SUTD), helping to establish an international research center while developing curriculum and recruiting faculty. SUTD decided to use course materials and a similar pedagogy to MIT, starting with the first incoming class in April 2013. All SUTD students are grouped in cohorts of 50 students to take their core classes in these interactive classrooms. Classes involve hands-on activities, such as simulations and problem sets, supplemented with mini lectures, vignette videos, small group recitations, hands-on demos, and concept quizzes.

Discussion 1

Faculty at all three institutions mentioned increasingly diverse student populations as motivation for a mode of instruction that may engage “students who didn’t traditionally feel comfortable in a lecture environment”, according to an administrator at NCSU. Both MIT and NCSU hoped to use this reform as a way to support students at schools with large student populations, where students may never individually approach a professor in a traditional class. Changing cultural factors also encouraged adoption at all three sites. An MIT professor recalls, “every MIT student is a possible scientist and there’s a shortage of them…. any time MIT loses a student, it’s not just a problem for MIT or that student, it’s a problem, a national issue“ which creates a responsibility for MIT to support student success. A faculty member at SUTD mentions changing technology and increasingly instantaneous access to information as accelerating the need for educational change.

Rogers acknowledges reforms are initiated through a variety of means. The perceived need for change often begins with a performance gap, a discrepancy between expected and actual performance or reforms can be initiated by wanting to test a new, potentially beneficial idea. In this case study, only MIT's decision to adopt was triggered by a pressing problem (high failure and low attendance rates) whereas NCSU and SUTD wanted to pioneer a new model of education. Departmental factors were key to successfully initiating change at this stage, facilitated by a "champion" (Rogers, 2003) who devotes himself to the cause. Beichner and Belcher both fulfill this role as "charismatic individual(s) who [throw themselves] behind an innovation, thus overcoming indifference or resistance that the new idea may provide to the organization" (Rogers, 2003, p. 414). Without a "problem" to fix at NC State, Beichner had to work to convince his colleagues to let him pilot the reform, especially administrators who thought SCALE-UP required more financial and staff resources than the traditional lecture. His strong background in education research, enthusiasm, teaching competence and charisma helped persuade the administration especially when he secured external funding for the project.

Under pressure from senior administration and faculty in other disciplines to fix the introductory physics courses, the MIT physics department strongly supported change, which helped Belcher initiate and maintain the reform effort. MIT's historical roots in physics education facilitated the matching phase, since interactive instruction was not new to the department. In the early 1990s, the Physics Department introduced two courses, 8.01x and 8.02x, where students actively learned introductory physics by building apparatus to measure fundamental constants and test conservation laws. Although this course was discontinued, its pedagogy paved the way for TEAL and many of its experiments were incorporated into this new reform.

Since MIT collaborated with SUTD on curriculum and pedagogy, administrators decided to teach core classes using a cohort style (similar to TEAL) while developing a vision for the university. This style of teaching seemed consistent with "we're a new school, trying new things". Additionally, TEAL's success at MIT made administrators confident that it would benefit SUTD students too. A professor recalls "the TEAL classroom experience is very highly regarded, very successful at MIT so I think it is definitely… [the] direction to go." The early decision alleviated a need for a major "change" since hired faculty expected to teach cohorts.

Research Question 2: Redefining/restructuring
Results 2

Although this paper treats SCALE-UP as the first generation "original" reform, other research-based reforms strongly shaped the innovation. Research on collaborative learning (Johnson, 1991), active learning (Felder & Silverman, 1988) and specific developments of physics education research, like the first studio physics model (Wilson, 1994) and Workshop Physics (Laws, 1991), influenced the development of the SCALE-UP pedagogy. When adapting these findings to teaching NCSU students, Beichner noted, "there's a wide dispersion in backgrounds and interest levels so I had to do something that involved the weaker students without boring the stronger students". He structured the groups heterogeneously and developed incentives to encourage the students to help each other learn. For him, this structured group work is SCALE-UP's defining characteristic, "the only thing I'm really particular about is if you tell people you are doing SCALE-UP and you're doing groups, then you need to do groups this way". Promoting face-to-face interactions and deemphasizing the traditional role of the instructor motivated the studio-style room design. Beichner wants faculty to consider "how the classroom design and furnishings, for example, affects their ability to have students do the things we want them to do: collaborate, communicate, problem solve".

MIT made significant modifications to SCALE-UP before trying it. Belcher and his MIT colleague, Dr. Peter Dourmashkin, visited NC State and decided to incorporate "the ideas of the tables, groups and the boards… So [the MIT] structure was very, very similar but the pedagogy and the way [they] taught was different and [they] had to make a lot of adaptations to the MIT student culture". MIT married SCALE-UP's studio-style instruction with Belcher's visualizations and Peer Instruction clicker questions (Mazur, 1997). Belcher and Dourmashkin started by assembling content: writing a textbook, reintegrating labs (introductory physics in the preceding thirty years had no lab component) and developing visualizations. The current format organizes content in ten-day modules, centered on completing problem sets, with one hour per week devoted to problem solving. In comparison to a flipped classroom model where students master the content prior to coming to class to ensure class time is spent on applying the information through activities, Belcher admits "I would say we're about half flipped, maybe one third flipped— we still have a lot of lecture" since students resisted a completely active model.

Similarly, SUTD decided to adopt a mixed pedagogy (for now) with 1.5 hours of lecture and 3.5 hours in a cohort classroom a week. The cohort sections typically begin with 15 minutes of mini-lecture before students work on concept questions and problem sets. Previous cohort schedules had more time for interaction (which the students liked) but when professors noticed the students did not come prepared to solve problems, they increased lecture time. Most of the course materials (textbooks, clicker questions and problem sets) come from MIT but "we added a lot of elements, like design projects, presentations, mini labs… to our format. These activities are designed to train our students in terms of presentation, problem solving, hands on activities and creativity". As an engineering-design school, SUTD added assessment where students build projects during class time to apply concepts, including interdisciplinary projects every semester.

Discussion 2

The major modifications to the reform made by MIT and SUTD prior to implementation supports Rogers' claim that when innovations are developed outside an organization with a flexible format, "a good deal of re-invention occurs until the organization's participants perceive the new idea as being theirs" (Rogers 2003, 426). Much of these modifications preemptively tried to fit the reform to the culture of the adoption site. Since MIT's students did not want to invest too much energy in their core classes and faculty are primarily assessed on their research productivity, TEAL was structured to ensure "it worthwhile to make students come to class and feel like they were learning and, at the same time, make it easy for faculty to teach in this environment". SUTD faculty frequently mentioned geographic cultural differences as justification for not eliminating the lecture completely as to not intimidate students who come from "places around the world… [who use] pretty traditional types of classrooms and may not find it easy to speak up".

Additionally, many of the implemented reforms bring together several developments from physics education research, shared through other research collaborations. Beichner's interest in active learning was highly influenced by a colleague at NCSU (Felder & Silverman, 1988), Belcher first heard about SCALE-UP during a research collaboration on another project, Dourmashkin introduced Peer Instruction with clickers after collaborating with its developer on a textbook project and the partnership between MIT and SUTD was created primarily for research purposes to begin with. Improving the amount of collaboration and quality of community of physics education researchers may accelerate increased implementation of research-based reform. The flexible curriculum of SCALE-UP and unique, extensive external collaborations at every site facilitate combining several pedagogical innovations into the implemented version.

Research Question 3: Clarifying/rountinizing
Results 3

To make SCALE-UP a permanent option for introductory physics at NCSU, Beichner collected quantitative and qualitative data to convince administration and his colleagues that this mode of teaching improved conceptual understanding, problem solving skills and attitudes toward science. This established SCALE-UP as a consistent offering at NCSU but unlike MIT and SUTD, faculty and administration do not anticipate it being the only option. An administrator recalls, SCALE-UP is good way to "create different tracks through the system" since "students have different learning styles and what works for one student may not necessarily work for another" so he believes it should not be the only available format. Once established, SCALE-UP has remained relatively stable with minor adjustments to the curriculum, activities and use of technology. In the future, Beichner anticipates pressure "from things like MOOCs (Massive Open Online Courses) and for-profit, probably online, universities" will cause brick-and-mortar institutions to think even harder about what they can add to an in-person learning experience, making social learning, like in SCALE-UP, even more important.

In contrast to the stability of SCALE-UP, TEAL evolved significantly to gain widespread acceptance as the permanent format for introductory physics. Belcher defended TEAL to students and the faculty who struggled to adjust to the new style (for more details, see Dori, 2003). The students objected publically, through articles in the school newspaper and with a petition to the department, displeased about having to come to class, work in groups and having to adjust to a different pedagogy. Belcher served as the charismatic, persuasive and persistent champion, defending the reform to the department as Dourmaskin and another instructor worked to fix these grievances.

Several key changes, mostly at the classroom level, successfully addressed student complaints. Initially, the instructors followed recommendations from physics education research to assign groups but found the strategy did not work for the MIT student culture. When instructors assigned groups and problems arose, students blamed their instructors but when students chose their own groups, Dourmashkin noticed, "they are responsible, they can't blame us and that changed the dynamic completely". To further improve interpersonal interactions, MIT made the undergraduate teaching assistant (TA) (which was lacking from the NCSU implementation) a prestigious and highly visible position. By assigning the TA to the same few tables for the whole semester, the TA builds a close relationship with students, can diagnose problems and direct students to help, a model that evolved into something similar to Peer-Led

Team-based Learning (Varma-Nelson, 2006). Having a graduate and six undergraduate TAs assist the professor increased personal attention during problem solving sessions, especially when board space was freed up so students could work in smaller groups.

These efforts to make class time worthwhile, increase personal attention, support the students and build solidarity in the classroom helped TEAL eventually become routinized in its current form at MIT, to an extent that "if you look at the student evaluations now, they like [TEAL] as much as when we had a good lecture". However, like Beichner, Dourmashkin anticipates the increasing popularity of MOOCs and the "flipped classroom" will change TEAL considerably in the next couple years. In anticipation, MIT is building a large learning asset management system so students can look at videos, read, do exercises and self-assess their progress against learning objectives prior to class.

SUTD learned from the challenges TEAL encountered so changes during these stages were less dramatic. To date, modifications involved adjusting the balance between lecture and cohort time to appease the students (who enjoyed the interactions) and the faculty (who felt the students came to cohort sessions unprepared). Similar to MIT, SUTD plans to eliminate in-person lectures by using videos and involve graduate students in teaching when graduate programs begin, in early 2014. Presently, three faculty members teach each cohort section (of 50 students) but utilizing PhD and senior students will allow students to have role models and extra resources for studying.

Discussion 3

During these stages, after initial departmental consent had been granted, classroom factors become more important as students and instructors clarify their roles in the reformed classroom. Having to increase lecture time since SUTD students did not come to class prepared echoes a trend found in the Taiwan TEAL implementations (Shieh, Chang & Liu, 2011) and (Shieh, Chang & Tang, 2010). Finding ways to better use the room (for example, freeing up more board space) and effectively utilize staff resources to create a classroom community were critical to improving the appeal and effectiveness of the innovation until it pleased faculty and students enough to become the standard format.

Rogers claims that the faculty champion also plays a key role at sustaining the innovation while working out the kinks during the clarification stage. Without dedicated champions like Beichner and Belcher, this major educational change might not have achieved sustainable use. Seymour (2001) found research credentials of the reformer could be more persuasive than either the data that support its efficacy or establishing students' approval, so Belcher's reputation as one of the principal investigators on Voyager (the spacecraft that explored the outer planets) ensured he was respected at MIT. In addition to having qualified and committed champions, both NCSU and MIT both kept data (Beichner et al., 2008; Dori & Belcher, 2005) that helped convince scientific colleagues the value of SCALE-UP style instruction.

All of these universities anticipate future changes, mostly due to shifts in the technological and educational ambient culture. However, these changes impact the organization as well as the reform, and at this stage, both will evolve together to ensure the institution provides quality instruction, in a contemporary context.

Research Question 4: How do the current implementations compare?

Results 4:

The percentage of class time spent in various activities is shown in Figure 3, based on one week of observation at each institution. Time logs determined the percentage of time the instructor presented information, students answered clicker or conceptual questions, students solved open-ended problems, students did hands-on activities and students presented to the class. At all of these places, how the class is run can vary significantly based on the topics covered so these findings may not accurately represent the semester average, especially since only a single section was observed at NCSU and SUTD. However, based on the classes observed, the percentage of lecture time increases dramatically from first to third generations, shifting toward more traditional techniques.

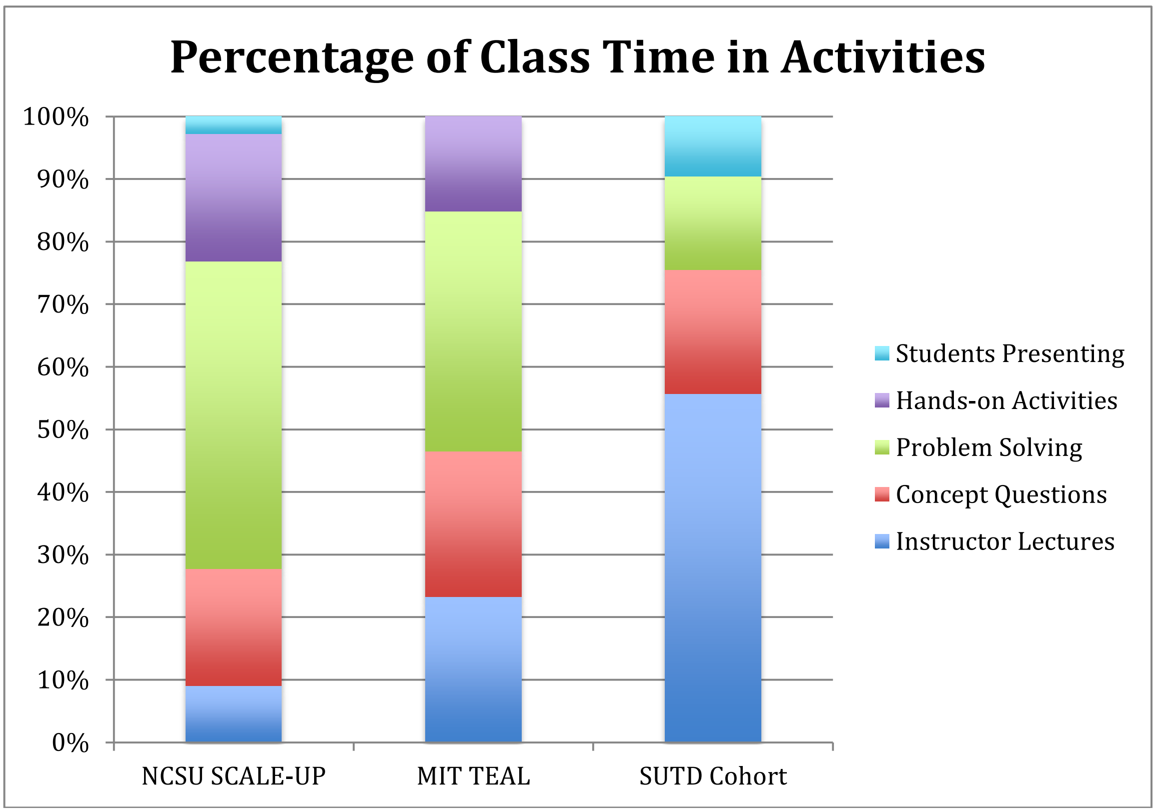

Figure 3: Percentage of class time spent in various instructional activities averaged over a week of observation.

Discussion 4:

Hands-on activities, in the form of experiments and computer simulations were absent from the SUTD implementation, partially because the experimental apparatus wasn't available. The SUTD classroom wasn't outfitted with computers for groups or individuals, which made online simulations or programming impossible without wheeling in laptops. In general, the technology in the SUTD classrooms was limited to whiteboards on the walls and projector screens and a microphone so students could share their solutions. Instead of an electronic clicker response system, they used numbers on badminton rackets to display the team solution to the instructor. Even without advanced technology, SUTD students spent the most time sharing their solutions to the class, proving instructors can have student-centered activities with limited budgets.

At NCSU and MIT, students used group laptops for hands-on activities. MIT had students using the computer for a circuit lab simulation during the problem solving session and the instructor did a demonstration with a real electric circuit but during the students didn't carry out any experiments themselves during the observations. The topic for the week of NCSU observations was quantum statistics, a challenging topic to simulate experimentally, so the students created a program to plot the distribution of states on a histogram.

Thus, the classroom resources, physics topic and the instructor's teaching style all affect how class is conducted however, these observations do confirm a trend toward increasingly traditional instruction, a finding consistent with educational reform literature (Hutchinson & Huberman, 1993).

Limitations

This exploratory case study provides examples of the successes and challenges during the initiation and implementation of a studio physics course at three large, research universities. Since researchers call for studies on the implementation of research-based reforms in complex institutional environments (Fairweather 2008; Seymour, 2011), this case study sought to identify contextual influences at various levels that influenced the process. Since only three institutions were examined for limited periods of time, results are not immediately generalizable but do provide further evidence of general themes elsewhere (Hutchinson & Huberman, 1993; Dancy & Henderson, 2010; Henderson, 2005, 2008; Henderson & Dancy, 2009) and brings up important considerations for possible future implementers.

A large-scale research project is currently being undertaken to survey secondary SCALE-UP sites about the implementation process to further verify and put this case study in perspective with quantitative trends. This model of dissemination can be further refined and validated once the qualitative, detailed insights of this case study are compared to and combined with global patterns.

Conclusions

The implementation process for SCALE-UP's transition to MIT and SUTD follows the five-step model proposed by Rogers. Although his model appears unidirectional, this case study reveals that secondary implementers constantly modify the reform, suggesting an iterative process. The second and third generation implementations re-invented the reform quite significantly to fit their local environment and ensure continued use, especially at MIT where key changes were needed to gain acceptance from faculty and students.

Re-inventing the reform increases the sustainability of a reform and can be critical to the innovation's survival (as seen at MIT, where a few changes were key to gaining student acceptance). However, secondary implementers should be cautious about how their modifications impact the effectiveness of a reform, especially if they revert to more traditional techniques. Even though SUTD imported much of their curriculum from MIT, they implemented a model with significantly more lecture so noticeable shifts toward traditional instruction can arise even in a "best case" scenario of reforms with high collaboration.

Cultural influences and historically traditional education systems may make SUTD particularly prone to re-introducing passive pedagogy. Since most Asian instructors have not been taught in interactive environments, professional development workshops and sharing physics education resources may be needed to familiarize faculty with what they should be doing and why.

In general, familiarity with the research behind the innovation may help organizations fit reforms to their institution's mission and personality without compromising on aspects that ensure anticipated benefits (for example, learning gains, attitudes toward science, problem solving skills). Encouraging secondary sites to document changes they made, the reason for modifications and the impact on outcomes could help. Future studies should monitor modifications made versus learning gains to investigate how secondary sites balance re-invention and sustainability.

Acknowledgements

This work was sponsored by the National Science Foundation's East Asia and Pacific Summer Institute, OISE fellowship. Similar work on "Sustainable Diffusion of Research-Based Instructional Strategies: A Rich Case Study of SCALE-UP" is currently being undertaken under NSF grant 1223405 with co-PI's Melissa Dancy, Charles Henderson and Robert Beichner. Thanks to administrators, faculty and students at North Carolina State University, Massachusetts Institute of Technology and Singapore University of Technology and Design for classroom observations and interviews. Much appreciation to Colleen Lanz who worked to establish inter-rater reliability for this study.

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