**ABSTRACT**

FOOTE, KATHLEEN TERESSA. Diffusion, Implementation and Reinvention of a University Physics Reform: The Case of SCALE-UP. (Under the direction of Robert Beichner.)

Educational researchers, including those specifically concerned with improving physics education, have spent a lot of time, effort and resources in developing research-based strategies to improve instruction. Many have documented how their techniques successfully improve various factors from conceptual learning gains to attitudes towards science and more. However, the majority of college science instruction still uses traditional techniques, implying these reformed materials have not achieved a widespread impact.

This dissertation uses SCALE-UP (Student Centered Active Learning Environment with Upside-down Pedagogies) as a case study to examine how research-based reforms spread and is implemented in real-life secondary sites. This reformed pedagogy and classroom structure has achieved a relatively large impact, used at over 300 departments at higher education institutions worldwide. We study how information spreads, what motivates an implementation, what affects the initial form of implementation and how sites make changes to achieve sustained use. Chapters 2 and 4 are exploratory, detailed case studies of implementation efforts at secondary sites. Chapter 3 presents results from a large-scale census that surveys people influenced by the reform to provide a broad overview of reform use at higher education institutions nationwide. Because of the lack of consensus in the field, these studies are exploratory with the goal of generating theory to describe real-life use of reform in natural settings. The goal of this dissertation is to identify how implementers learn and implement reforms, identifying factors that lead to modifications along the way.

We found interpersonal networks were an important source of information about the reform. More importantly, how implementers receive information and make sense of the reform impacts curriculum development efforts. At the sites studied in Chapter 2, implementation was an iterative process with instructors constantly making modifications to better fit the reform to their students, teaching style and instructional setting. In Chapter 4, instructors developed a working form of the curricula during their first or second semester teaching the course then avoided making significant changes.

A unique aspect of the SCALE-UP reform is the structural changes required to create a studio-style classroom and class time to integrate lecture, laboratory and recitation sections of a science course. The census revealed the reformed classroom is also associated with higher levels of active learning and study 3 revealed that instructors to radically renovate their curricula to fit the new studio space.

This work has important implications for researchers, curriculum developers and instructors interested in spreading reformed teaching. Utilizing interpersonal networks, including preexisting ones, could aid dissemination efforts. Reforms are modified, which can be positive in many ways, however misunderstandings about the reform can lead to non-productive modifications. Thus, researchers should be aware of how instructors understand the reform so they can anticipate and eliminate any misconceptions that may lead to nonproductive changes.

This exploratory work opens up many potential avenues for future research. The case studies in Chapters 2 and 4 focuses on relatively successful sites that have achieved widespread, sustained use in introductory physics. In the cases documented here, knowledgeable, self-motivated instructors initiated change and the literature suggests the process may be quite different for hesitant, mainstream adopters. Future work should explore the dissemination and implementation among "more typical" faculty members, especially if they are expected to help develop curricula. A particularly fruitful aspect of this process may be investigating instructor's "sense-making" process since researchers have more control over how they frame and present research-based resources than other situational factors.

Diffusion, Implementation and Reinvention of a University Physics Reform:
The Case of SCALE-UP

by
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**BIOGRAPHY**

Kathleen Foote was born in Farmington, Connecticut to Lauren and James Foote on June 28, 1988. As the daughter of an engineer and nurse, she has always been interested in math and science but also interested in making the world a better place for the people in it through education and global awareness. From the first day of kindergarten, she knew she wanted to teach. From the first day of high school, she knew she wanted to teach physics.

After graduating high school, Katie attended Providence College with a double major in applied physics and secondary education in physics. She enjoyed her time teaching in high schools around Rhode Island but felt something missing in traditional science classes. A summer research opportunity at the University of Minnesota exposed her to the field of Physics Education Research and it felt like a perfect fit. She wanted to learn more physics and hoped to improve education in a field that she loved but many do not appreciate.

She joined the physics graduate program at NC State with the intention of learning new pedagogical techniques and conducting research in physics education under the direction of Dr. Beichner. In addition to developing research skills, Katie took advantage of professional development opportunities including transitioning a traditional modern physics course into a more active, studio-style course, as part of the Preparing the Professoriate program. After an initial interest in gender issues, her research interests eventually turned to studying the spread of research-based reforms. Collecting data for this project involved traveling to several universities, including across the seas to Singapore. This project revolutionized the way she thinks about educational reform and hopes readers and the physics education community finds it similarly worthwhile.

**ACKNOWLEDGMENTS**

As the crown jewel of academics is nearly in reach, I have spent time reflecting on the past two decades I have spent in school. I never had trouble memorizing facts, applying equations and writing papers and through college, my role models were teachers who could explain things efficiently, taught me long division and made physics “phun”. Graduate school was the first time I was ever asked to do something *new* and now I am most grateful for all the people who did *not* tell me the answer.

As with any journey worth undertaking, moving toward a PhD had its ups and downs, its moments of confusion and clarity and its successes and failures. When you start to specialize for a PhD, your path diverges from all your predecessors and suddenly you seem alone on an isolated island of expertise. At times, I felt like I was swimming in unchartered seas of unfamiliar literature, following ideas down twisted paths of tangentially-related topics, standing in caves devoid of inspiration and I fell down more than once (literally… and broke three bones during my graduate career). Sometimes all I wanted to know was where to go next but no one could (or would) point me in a definitive direction. While the lack of immediate gratification felt frustrating, I knew I had support and encouragement throughout the process. I am infinitely appreciative of the people who stepped back and let me figure these things out for myself because all that I learned about physics and education pales in comparison to what I learned about life.

That being said, I did receive tangible guidance, support and advice from countless sources. Thanks to #NSF grant 1223405 which funded much of my research and taught me how to undertake a large-scale project. I thoroughly enjoyed working with some of the researchers I admire most: Charles Henderson, Melissa Dancy, my advisor Robert Beichner and post-doc Alexis Knaub. A National Science Foundation fellowship EAPSI OISE-13 funded my summer research in Singapore and part of the data collection for Chapter 2.

Much appreciation goes to my thesis advisor, Robert Beichner and the NC State STEM initiative for connecting me to people and funds for me to pursue my research interests, from Massachusetts Institute of Technology to Japan.

My project involved reaching out to instructors and institutions for data collection and I am infinitely grateful for the faculty members who invited me into their classrooms, took time to talk to me and share classroom resources.

I was fortunate to be surrounded by outstanding graduate students and faculty while conducting my research. Thank you to the committee members who I have not yet mentioned: Albert Young, with whom I spent three semesters teaching a SCALE-UP-style modern physics course with, Michael Paesler who generously still does PER after retiring and Margaret Blanchard who always sheds valuable insight on my work from a science education perspective. I also appreciate the feedback, criticism and encouragement that I received from the NC State physics education research group, including past and present members. Mary Bridget Kustusch patiently answered many of my questions as a prospective student and is part of the reason I decided to come to NC State. Brandon Lunk and Meghan Westlander enlisted my aid with inter-rater reliability, which help build skills for when it was my turn. Colleen Lanz helped me establish reliability for my study in Chapter 2 and has accompanied me throughout the graduate school journey.

Last but definitely not least, thanks to my family and friends who kept me sane throughout the process. My parents, Lauren and Jim, have always been a huge inspiration for me and I appreciate their interest and encouragement every step of the way, especially when they volunteered to read my long and boring fellowship applications and research papers. Thanks to my siblings, Susie and Jimmy, for staying in touch and getting closer even when geographical distances got greater. Finally, I am grateful to my Aunt Meredith and Grandma for their uncompromising support through my seemingly eternal education.

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# CHAPTER 1: Introduction And Literature Review

This chapter will provide an overview of the motivation, large-scale literature review and relevant theoretical constructs underlying this study. Then, the second half of this chapter will discuss the structure of the dissertation and contents in more detail.

## I. Motivation

Over the past several decades, countless efforts have been made to develop innovative teaching strategies to improve science, technology, engineering, and math (STEM) education for all students. Countless publications reveal that these alternative teaching methods can successfully boost learning gains while improving a host of affective factors (Wieman 2007, Redish 2003, Docktor & Mestre 2011). However, the combined efforts of researchers, federal agencies, private foundations, and internal institutional programs have achieved little overall change in STEM teaching in higher education, especially large research universities (Wieman, Perkins & Gilbert 2010, Dancy and Henderson 2010, Handelsman et. al. 2004, Henderson and Dancy 2009, National Research Council 2003, Redish 2003). After developing a new innovation, many researchers disseminate their findings primarily through one-way transmission methods, such as publishing a paper or giving a talk at a conference (Khatri, Henderson, Cole & Froyd 2013) but this traditional Development and Dissemination model rarely leads to widespread adoption (Fixsen, Naoom, Blase & Friedman 2005).

Rogers (2003) acknowledges, “awareness of a better way to do any task does not lead to its natural adoption” because people subjectively evaluate the new approach through their own past experiences, perceptions and peer feedback instead of relying strictly on rational arguments. Wienman et al. (2010) noticed, “while research and data on student learning are important and useful, they were seldom compelling enough by themselves to change faculty members' pedagogy, particularly when that change conflicted with their beliefs about teaching and learning" (p. 13) and that professors' "pedagogical discontentment" in their own classes was a far more important factor when considering change (Southerland, Sowell, Blanchard & Granger 2011). Adopters will filter the information and advice they receive to consider, try, adopt and maintain selectively that fits with their perceived needs, priorities and circumstances (Green, Ottoson, Garcia & Hiatt 2009). Thus, it will be important to investigate how instructors understand a reform and what information effectively motivates them to make a change.

Even if instructors attempt to use a reform, the implemented result can deviate from the intended use or take on new forms (Henderson & Dancy 2009, Henderson 2005) and this new model should explicitly account for the implementers' tendencies to make modifications. Rarely does a reform fit perfectly into the user environment so, almost inevitably, users modify, alter and refine the reform to fit their local setting (Barley 1986). These adaptations can have mixed results.

On the positive side, faculty are more often open to trying flexible reforms that allow adaptations according to faculty expertise (Henderson & Dancy 2008, Penberthy & Millar 2002, Silverthorn, Thorn & Svinicki 2006). As Cohen and Ball explain, "teachers view themselves as independent, autonomous professionals… Even the most obedient and traditional teachers observed, enacted policies in their own ways and were proud of their contributions" (1990 p. 253).

Even more general than educational innovations, researchers have found personalization of technology improves user satisfaction (Ives & Olson 1984). In addition to increasing faculty openness to a reform, reinvention allows users to take ownership of an innovation, improving sustainability. Flexibility in adapting a reform may encourage customization of the innovation to fit local or changing conditions and make the reform more responsive to current and future problems (Rogers 2003).

However, especially with more complex and harder to understand innovations, users can make modifications that compromise effectiveness. Many educational reforms have ended with the innovative instruction gradually fading until it becomes indistinguishable from initial instruction (Hutchinson & Huberman 1994). For example, researchers studying learning gains at a secondary site found improvements after using Interactive Lecture Demonstrations were "nowhere near" those claimed by developers (Sharma et. al. 2010) and did not know how to achieve promised results at their institution. Thus, more research is needed to understand the role of reinvention so secondary implementers can achieve increased satisfaction and sustainability without sacrificing educational benefits. My dissertation explicitly monitors modifications in all three studies and focuses intensely on how instructors come up with a curriculum to accompany the reform in Chapter 4.

Despite making modifications to adapt to their local situation, many faculty members still discontinue use after trying these instructional strategies (Henderson, Dancy & Niewiadomska-Bugaj 2012). Since this "show them and they will adopt" does not promote productive, sustained use of reform, the literature calls for a more robust, research-based model of change (Fairweather 2008, Seymour 2002, Henderson, Beach & Finkelstein 2011).

To come up with this model that accounts for "enacted use", we must closely examine implementation at secondary sites. Although these are the most common type of reform adopters, very few studies examine how secondary sites initiate, implement and use innovative pedagogies.  Often, developers do not articulate the underlying organizational support structures needed to ensure outcomes.  This can contribute to disappointing results when secondary sites try to use the same reform with different students, instructors and educational settings (Finkelstein & Pollock 2005, Pollock & Finkelstein 2008, Saul & Redish 1997, Sharma et al. 2010).  To identify what went wrong, one must investigate the mysterious "black box" implementation stage (Fullen & Pomfret 1997, Fixsen et. al. 2005. Fixsens et al. (2005) urge researchers to study this process at secondary sites to figure out core intervention components so other implementers know what can be adapted to local settings and what must be preserved.  Only by examining the complexities of incorporating innovations into new settings can we generate relevant, believable and actionable advice for future implementers.

"Enacted use" can vary significantly from the developer's intentions especially since the literature rarely explicitly advises secondary sites on how to overcome challenges and achieve success in different environments.  Most of the available literature on innovative pedagogies comes from the "best-case scenario" of development sites that have access to grant funding, a project team, faculty release time and education experts that contribute to published success rates.   Similarly, Green et al. (2009) explains that much of the existing innovation literature holds little practical value to secondary implementers since studies have

> "been conducted in highly controlled circumstances, which maximizes its internal validity but limits its external validity and perceived relevance and fit in practice.  To implement more evidence-based practice, we need more practice-based evidence" (p. 168).

This thesis is written during an exciting (and intimidating) time for education. Universities are facing increased competition, greater numbers of non-traditional students, ageing facilities and decreased governmental funding (Douglass 2010, King & Sen 2013, Jones, Ramanau, Cross & Healing 2010). Online universities, Massive Open Online Courses and other freely available course materials put even more pressure on administrators to defend the unique value of a brick-and-mortar education (Martin 2012). Economic pressures, both nationwide and within schools, push instructors to use class time and resources effectively. Faculty members are increasingly expected to cut failure and withdrawal rates, especially in introductory STEM courses, which are gatekeepers for preparing the scientifically literate workforce this nation needs. These growing concerns have placed education in the forefront of national conversation and demanded change.

Faced with this rising crisis, many college administrators have begun to search for strategies to improve institutional quality and effectiveness. Fortunately, they have thousands of research-based reforms to choose from (Docktor & Mestre 2011, Redish 2003) and studies have documented success at development sites. However, for these reforms to facilitate wide-scale educational transformation, the nature of implementing reforms by secondary users must be better understood. Subtle contextual factors, broader institutional structures, social networks and faculty behavior all impact the enacted form of the educational innovation. Thus, we need to consider all these factors, and the interactions between them, to understand how reforms are put into use at secondary sites.

This thesis aims to inform the development of an evidence-based theory of diffusion that allows for reinvention and adaptation by closely examining enacted use of SCALE-UP in a variety of natural instructional environments as well as relating more detailed findings to a snapshot of nationwide use. Dr. Robert Beichner developed SCALE-UP ("Student Centered Active Learning Environment with Upside-Down Pedagogies") for large enrollment university physics courses at North Carolina State University in 1997 (Beichner et al. 2007, Beichner 2008). This fairly open-ended reformed pedagogy and classroom design blends several research-based strategies and has successfully crossed disciplines and continents for use in at least 314 departments at 189 higher education institutions worldwide *(see chapter 3)*. Some of SCALE-UP's most essential elements include the promotion of social interactions among students and teachers, the integration of lab and lecture, and a focus on developing conceptual understanding and critical thinking skills.

SCALE-UP is worthy of examination for multiple reasons. When implemented well, Redish (2003) found that radical reforms, like SCALE-UP, lead to higher learning outcomes than more modest reforms. A variety of data sources reveal SCALE-UP effectively improved students' problem solving ability, conceptual understanding, and attitudes toward science, while promoting success in later courses and reducing attrition rates (Beichner et al. 2007, Beichner, Saul, Allain, Deardorff & Abbott 2000). To spread these benefits amongst a wider population, we must understand how to spread this reform (and others) successfully to secondary sites.

SCALE-UP re-envisions the classroom environment to facilitate interaction; round or D-shaped tables, whiteboards on walls and technology with projection capabilities promote collaboration and sharing of student work. No obvious "front" of the room encourages instructors to minimize time lecturing and instead circulate and engage student teams in

Socratic dialogue, real-world problem solving and technology-rich activities. Reforms that involve structural changes, like SCALE-UP, often require a high up-front investment that we hypothesize will impact the implementation process by involving a commitment by administration.

The extensive and relatively informal dissemination of this radical course change has led to fairly significant variations in implementation, providing a wide variety of instructional interpretations to investigate. SCALE-UP is not discipline or curriculum specific, which allows us to explore how instructors chose implementation materials. The large number of secondary sites allows us to study implementation in a variety of settings, stages of implementation and at locations with varying intra-institutional spreads. Additionally, SCALE-UP has been disseminated through a variety of formal and informal means, both by the developer and by advocates at other sites.

Examining how information reaches and transfers into use for SCALE-UP use in environments fundamentally different than the development site will help reform developers understand how their reforms are used in natural settings. Identifying the reason behind common adaptations will help identify which aspects of reform should remain flexible and where they might need to intervene to dissuade users from making non-productive changes. Understanding how reformers learn about this innovation and try to use it will hopefully have implications for the dissemination of other reforms.

Chapter 2 will follow the SCALE-UP reform through three generations of implementation, trace how the reform transforms from site to site and shed insight on how implementations mature as spread farther from the development site. Chapter 3 will report results from a large-scale census of current SCALE-UP sites, to quantitatively characterize the stage of diffusion across disciplines as well as identify characteristics of reform users and implementations. Finally, Chapter 4 will examine how reform imitators make sense of the reform and create a curriculum for use at their institution.

## II. Large Scale Literature Review

### Scope of Literature Review

Even though people have been conducting innovation diffusion research for decades, the field still lacks a single, unified, widely accepted theory of implementation. Researchers have approached this issue from a variety of disciplines, including rural sociology, marketing, health policy, and educational reform, and the literature consists of a mind-bogglingly large collection of non-generalizable theories, each addressing a different aspect of the diffusion process or a different type of innovation. Klein & Sorra (1996) point out,

> "Because each implementation case study highlights a different subset of one or more implementation policies and practices, the determinants of implementation effectiveness may appear to be a blur, a hodge-podge lacking organization and parsimony. If multiple authors, studying multiple organizations, identify differing sources of implementation failure and success, what overarching conclusion is a reader to reach? The implementation literature offers, unfortunately, little guidance" (p. 1059).

Furthermore, although case studies determining conditions for innovation *adoption* are abundant, innovation scholars have long lamented the lack of research on the *implementation* stage (Beyer & Trice 1978, Hage 1980, Roberts-Gray & Gray 1983, Tornatzky & Klein 1982) which is acknowledged as a critical period for complex organizations innovations like SCALE-UP (Van de Ven & Rogers 1988).

This literature review will provide a basic overview of diffusion of innovation theory according to Rogers (2003) whose book, now in the 5th edition, "is the closest any researcher has come to presenting a comprehensive theory of diffusion" (Surry & Farquhar 1997 p. 3). Then, we will present literature pertinent to understanding the issue at hand, concentrating on the implementation/reinvention process of complex process-based innovations in organizations, like SCALE-UP. We are particularly interested in implementations where the adopting unit

> "is the team, department or organization in which various changes in structures or ways of working will be required. In such circumstances, there is almost always a formal decision-making process, an evaluation phase or phases and planned and sustained efforts at implementation" (Greenhalgh, Robert, Macfarlane, Bate & Kyriakidou 2004 p. 600-601).

In these situations, complicating factors due to the larger adopting unit means much of the literature on simple, product-based innovations adopted by individuals cannot be generalized (Greenhalgh et al. 2004). Therefore, this review will primarily employ literature surrounding the adoption of complex, organizational innovations that require active and coordinated use for adoption.

This section will wrap up with more extensive background on SCALE-UP, its pedagogical goals, relevant research-based strategies and relevant implementation literature. In order to pick out the "core implementation" features of the reform, it is important to understand what the reform aims to accomplish and how the development site and secondary sites achieve those goals. Relevant implementation literature helps predict which elements may transfer more naturally than others.

**A. Diffusion of Innovations And Communication Channels**

According to Rogers (2003), *diffusion* is the planned or spontaneous process in which an innovation is communicated through channels over time among members of a social system, ultimately changing the structure and/or function of this system. Diffusion research, at its simplest, investigates how the features of the innovation itself, the communication channels, members of the social system and a multitude of other factors, interact to facilitate or impede the adoption of a specific product/practice amidst a particular adopter group (Rogers 2003). Since an innovation relies on a social system to spread, much of the innovation's success depends on its compatibility with the past experiences of individuals in that system.

Lomas (1993) was one of the first to define a clear distinction between diffusion and dissemination and most researchers who draw a distinction follow her definition. She defines diffusion as a passive concept that is largely unplanned and uncontrolled, so it typically reaches people who are already open to and seeking out the message. She contrasts this with the more active concept of dissemination, which "not only implies a more aggressive flow of information from the source… and a targeting and tailoring the information for the intended audience." (Lomas 1993, p. 226) Although this definition has been influential in the field, Rogers uses dissemination and diffusion interchangeably to describe the transfer of information. Thus, I will also not distinguish between the terms in this work.

In this social process, awareness about an innovation spreads through communication channels. Participants communicate to create and share information about an innovation to reach a mutual understanding and reduce their uncertainty before they decide to adopt. Often communication is more effective amongst *homophilious* members (who share certain beliefs, backgrounds, levels of education, socioeconomic status, etc.) but often diffusion happens between *heterophilous* participants, where a knowledge imbalance causes information to flow mostly in one direction (Rogers 2003). As will be discussed in the sense-making framework portion of this chapter, the expert-novice knowledge imbalance can lead to misinterpretations of the reform (Spillane, Reiser & Reimer 2002). Futhermore, Mintrom & Vergari (1998) claim that most people considering adoption want practical information from users in similar situations to themselves;

> "Rather than rely upon mass-media channels or the outcomes of scientific investigations, most potential adopters base their judgments of an innovation on information from those who have sound knowledge of it and who can explain its advantages and disadvantages" (p. 124).

McLaughlin (1990) urges policy makers to look beyond formal policy structures to spread information and, instead, utilize preexisting professional networks as a vehicle to spread innovations, as these natural, more homophilious networks can lead to more sustainable change. This is also why secondary sites should share their successes and failures since their experiences can be more relatable than the best-case scenario of development.

This information can be used to improve research-based reform efforts at colleges and universities. Traditionally, Principal Investigators and reform developers use one-way transmission modes for dissemination (publishing a paper or giving a talk at a workshop) but Rogers (2003) recommends researchers need to do more than just spread awareness of a "better" way to do things. Similarly, with regards to physics education, Henderson & Dancy (2007) proved that showing faculty members that lecturing does not work is counterproductive. Instead, Vicens & Caspersen (2013) suggest appealing to classroom experiences faculty members can relate to then "dilute out the principles of student-centered active learning so that scientists feel they get their most urgent needs met first" (p. 4-5). For example, demonstrating the reform addresses the problems that faculty members witness in their classes: students are not engaged, motivated and do not do their homework (Wieman et al. 2010). Overall, this theory suggests successful dissemination needs to facilitate practical information sharing that address issues that faculty members perceive to be relevant (Khatri et al. 2013, Mintrom & Vergari 1998) with information exchanged amongst faculty members who share a common understanding, opposed to more formal channels.

## B. Dissemination of Innovations in Organizations

### Rogers 5-Step Innovations in Organizations Adoption Model

Rogers started thinking about the diffusion of innovations in organizations when he realized that organizational adoption is required before individuals even have the option to adopt certain products. For example, if a district does not provide computers to the schools, then teachers do not have the option of teaching with computers (Rogers 1983). A major turning point in innovation research was when Zaltman, Duncan & Holbek (1973) published *Innovations and Organizations* that explored this topic in detail and inspired a 5-step innovation process for organizations (Rogers 2003).

First, an organization undergoes *initiation* that involves gathering information, conceptualizing and planning for the adoption of an innovation. The initiation phase is further subdivided into two stages: agenda-setting and matching. *Agenda-setting* occurs when the organization defines a problem and perceives a need for an innovation. Innovation can be triggered by a performance gap, lower than expected performance, knowledge of an innovation or opportunistic surveillance for beneficial ideas. Berman & McLaughlin (1976) found that the nature of the decision to adopt played a critical role throughout the implementation of federally funded projects in the RAND study. Projects started by opportunism related to the availability of funds evidence little local commitment while reform efforts started to solve a problem led to greater changes.

Next, during *agenda-matching,* an organization matches their goals with an innovation to determine how well they fit before attempting an implementation. Bourdenave (1976) found that "innovation-system fit" between the innovation and its potential context, is generally a more valid and useful construct than the fixed, context-independent "innovation attributes" mentioned in earlier literature (Klein & Sorra 1996).

A satisfactory completion of these two steps leads to the *implementation* phase when an organization puts the innovation into use. This phase is subdivided into three steps: redefining/restructuring, clarifying and routinizing.

During *redefining/ restructuring***,** the innovation is re-invented to accommodate the organization's needs and structure more closely. "Adaption is precipitated by implementation misalignments— mismatches between the technology and the organization recognized at the time of initial or trial use" (Rogers 2003 p. 255). Usually both the innovation and the organization change in this process, as both undertake "cycles of adaption" to ensure a better fit (Van de Ven 1986, Leonard-Barton 1988, Ettlie, Bridges & O'Keefe 1984). Adaption during this stage helps organizations takes ownership of the innovation, especially if it originates outside the innovation (Rogers 2003). Thus, reinvention can aid sustainability because "when an organization's members change an innovation as they adopt it, 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, O'Loughlin, Renaud, Richard, Gomez & Paradis 1998). Furthermore, Ives & Olson (1984) demonstrate that user participation in customizing a technology to their needs improves user satisfaction. Other literature confirms this result carries over to education since faculty members are more open to adaptable reforms that acknowledge their expertise (Henderson & Dancy 2008, Penberthy & Millar 2002, Silverthorn et al. 2006).

Next, *clarifying* occurs as the organization puts the innovation into more widespread use and its significance gradually becomes clearer to organizational members. When an organization first introduces a reform, it usually has little meaning. During this stage, members figure out how an innovation works, how it impacts the organization as a whole and how they are personally influenced. This stage may involve working through misunderstandings or unwanted side effects, sometimes through the aid of a "champion." Since probability of opposition is higher in larger adopting units, champions play an important role for organizational innovations. These individuals throw their weight behind an innovation, thus overcoming resistance that the new idea may provoke (Schon 1963, Rogers 2003, Greenhalgh et al. 2004) especially as people try to figure out how an innovation may affect them during the clarifying stage.

The *routinizing* stage completes the innovation process when the innovation has become incorporated into the regular activities of the organization and has lost its separate identity. Sustainability that accompanies routinization is achieved partly by *participation* in the innovation process (Fullan & Miles 2002, Wieman et al. 2010). Reforms have the greatest likelihood of success when a cross-role group (such as teachers, department heads and administrators) collaborates to create change. If the implementation decision involves only one or a few powerful individuals, sustainability is at risk if key figures leave (Rogers 2003). Other factors that influence sustainability is (1) the degree of reinvention (2) the fit between the intervention and the organization and (3) involvement of the local champion (O'Loughlin et al. 1998).

Although this can guide our thinking about stages in the organizational innovation process, several researchers warn against taking this process literally at the organizational level, "the move from considering an innovation to successfully routinizing is generally a nonlinear process characterized by multiple shocks, setbacks and unanticipated events" (Van de Ven et al. 1999). Polley, Garud & Venkataraman (1999) point out that the model holds better in managerial situations when executives make top-down decisions for the whole company but decision making in schools can be more complex (Etzioni 1961, Hage 1999) since each faculty member has more autonomy to respond the ideas, information and other social forces. Thus diffusing the innovation within schools may take more effort (Frank, Zhao & Borman 2004).

Although researchers criticize Rogers' model, neither does the literature agree on a suitable alternative and lacks a unified overarching framework. The empirical literature consists largely of single case studies that uncover an extensive list of "implementation policies and practices" including innovational, organizational, and managerial characteristics that may influence innovation use. Examples include training in innovation use (Johnson & Johnson 1994, Fleischer, Liker, & Arnsdorf 1988), adequate support services (Surry & Land 2000, Balwin & Ford 1988), time to experiment with the innovation (Zuboff 1988), praise from supervisors (Klein, Hall, & Laliberte 1990) and financial incentives for innovation use (Wienman et al. 2010) and more.

**C. Implementing SCALE-UP and Related Instructional Innovations**

In 1995, at North Carolina State University, Dr. Robert Beichner developed SCALE-UP (originally "Student-Centered Activities for Large Enrollment Undergraduate Programs") as an alternative to the traditional lecture approach for introductory physics. Before SCALE-UP, instructors who wanted to incorporate active learning into their large enrollment classes typically were limited to implementing interactive lecture activities like Peer Instruction (Mazur 1997) and Interactive Lecture Demonstrations (Sokoloff & Thornton 1997) and then reserving hands-on activities for smaller laboratory or recitation sections. SCALE-UP provided an alternative, allowing instructors of large-enrollment courses to replace a lecture/recitation/laboratory model with studio instruction, where the same group of students and instructors engaged in activity-based instruction for 4-6 hours per week. Now SCALE-UP has spread to all class sizes and dozens of disciplines *(see Chapter 3)*.

The SCALE-UP model focuses on the design of the physical layout and the nature of interactions in the classroom without using a specific curricular approach. This allows instructors to customize their curriculum in engaging their students with various activities that accommodate varying abilities, interests and needs. The developer borrows from preexisting research-based instructional materials for the North Carolina State University implementation and recommends that secondary sites also use research-based materials (Beichner et. al. 2007).

Pedagogical goals of SCALE-UP (which should be common across all implementations) include creating a learning environment in students collaborate with their peers to question, teach one another and present their work to the class. The developer recommends instructors to reduce lecture by replacing it with activities and coach students to answer their own questions.

This section describes relevant research-based materials that influenced or are used in SCALE-UP classes, since they are relevant for understanding how modifications compare to the original reform (especially in Chapters 2 and 4). Some of these research-based materials can be implemented almost as designed by the developer but others may need considerable modification for successful use in the local SCALE-UP setting. SCALE-UP's flexible approach and lack of specific curriculum encourages instructors to tailor their reform use to their learning objectives, student population, class size and classroom environment. The development website contains instructional materials in introductory physics (designed for 99 students) but lacks systematic suggestions for how resources may be altered for smaller classes or different resources. Chapter 4 explores how instructors at secondary sites create their own curriculum to accompany their implementation of the SCALE-UP pedagogy.

The following literature review describes key components of the pedagogy (cooperative learning and active learning) and learning goals (conceptual understanding and problem solving) of the SCALE-UP approach, including relevant research-based educational materials. When appropriate, the original context for use of these reforms will be presented, followed by recommendations for integrating these strategies in a SCALE-UP environment, if available. This section will conclude with specific issues related to implementing SCALE-

UP at secondary sites. The composite papers do not have space for detailed descriptions of the underlying components of SCALE-UP but they are included here since this is important for understanding how modifications made by secondary users could influence the implemented reform.

**1) Collaborative Learning**

Collaborative learning restructures the educational environment so learning is not an individual activity but instead takes place as students work in small groups, defining problems, posing questions, gathering data, interpreting findings and sharing conclusions with team members and classmates. Promoting interdependence encourages collaboration as students work to construct and share knowledge, taking ownership for their participation and contributions to the class (Johnson & Johnson 1978). As the students take a more active role, the teacher facilitates group effort, providing necessary resources to ensure success. Collaboration helps students understand and master the vocabulary, methodology and the goals of knowledge in a particular discipline.

SCALE-UP students are strategically grouped in teams of three, an "optimal size" large enough to generate diverse ideas but small enough so everyone is actively engaged and contributing (Heller and Hollabaugh 1992). Groups are designed to be heterogeneous in academic background, containing a top-, middle- and bottom-scoring student (usually according to pre-test score, exam grade, course grade, or GPA). Heller and Hollabaugh (1992) found these groups performed better than homogeneous groups. The top student may provide leadership and direction while the low or medium ability student keeps the group on track, clarifies concepts and/or points out ideas others might have missed. It is recommended female or minority students are not alone in the first grouping, since they are often not as influential in team settings as they should be (Heller et. al., 1992).

At the beginning of the semester, training in group functioning and group roles sets expectations for how students are expected to meaningfully contribute to group work (Heller et al., 1992). Group roles can include (a) the manager who plans the approach; (b) the skeptic, who questions the plan and assumptions; and (c) recorder who organizes and reports the results of discussion. Students often spontaneously adopt these roles but instructors are encouraged to assign and rotate these roles. This encourages students to examine problems from a variety of perspectives while decreasing the likelihood of one student dominating group work.

*Cooperative Learning* (CL) is defined as students working in groups on structured tasks. According to Johnson et al. (1991), there are five critical characteristics to doing this successfully:

1) *Positive interdependence:* Team members have to rely upon one another and benefit from working together.

2) *Individual accountability:* Each member is responsible for mastering the material and contributing equally to the group work.

3) *Face-to-face interaction:* Most of the group effort must be spent with members working together.

4) *Appropriate use of interpersonal skills:* After receiving instruction, members must practice leadership, decision-making, communication and conflict management

5) *Regular self-assessment of group functioning:* Groups need to evaluate team functioning and identify ways to improve

SCALE-UP uses group contracts, group evaluations and teamsmanship bonuses on exams and individual quizzes (where students attempt the quiz individually but can consult the group for a small penalty) to promote this kind of collaboration. Formal and informal collaborative learning activities like think-pair-share, cooperative note taking, think aloud group problem-solving and jigsaw activities encourage collaboration within and between groups. For a more complete description of these classroom practices that facilitate these aspects of CL, see Beichner et al. 2000.

The room and classroom equipment were designed to promote collaboration. The 7-foot round tables were empirically optimized for group interaction in large classes (Beichner et al. 2007)- large enough for sufficient workspace during activities but small enough so students can communicate across tables. Sharing key resources, like computers or lab equipment, and writing on white boards also promote group cohesion by creating positive interdependence. The tables seat three groups of three students, and places different groups in close proximity so teams can help each other. The instructor can promote intergroup collaboration by having teams evaluate each other's work or by creating assignments where three teams work on related problems and share resources.

Groups typically rotate 2-3 times per semester and Beichner (2008) recommends groups should still be formed according to ranked thirds. However, anecdotally "it is no longer necessary to carefully match women and minorities. Somehow, students find a way to make their voices heard within a group after only a few weeks" (p. 9).

Two examinations of CL use amongst secondary schoolteachers (Ishler, Johnson, & Johnson 1998, Abrami et al. 2004) may have implications for implementing SCALE-UP, although secondary school teachers have more background with educational underpinnings than a typical physics professor. Both studies found teachers needed to be empowered to believe CL will work in their situation and supportive communities at their institution may help; "it may be useful, but not sufficient, to show teachers how successful others have been with CL techniques... follow-up training for skill refinement and for adaptation of the innovation to a teacher's particular situation may also be essential" (Abrami et al. 2004 p. 211). As collaborative learning is central to the SCALE-UP pedagogy, these recommendations may carry over. Proof that collaborative learning works somewhere may not convince faculty to risk trying CL in their classrooms. Adopters may need specific guidance, support and empowerment to convince them it can work in their situation before they decide to adopt.

**2) Active Learning**

Felder and Brent's models of student intellectual development (2004a) and implications for the classroom (2004b) recommend students should be presented with a variety of learning tasks to simultaneously challenge and support them in a student-centered learning environment. SCALE-UP was developed under the assumption that "the more you do, the more you learn", and Figure 3 summarizes this philosophy graphically, depicting Edgar Dale's (1969) hierarchy of learning activities and their impact on long term knowledge retention.

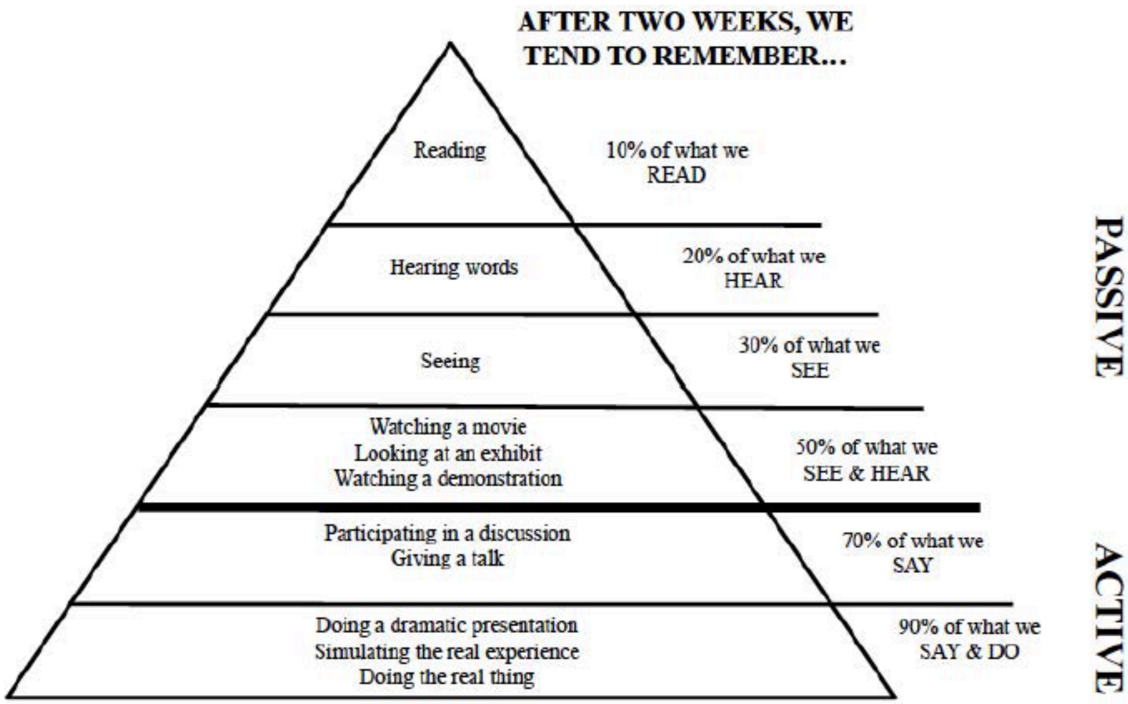


Figure 1: Dale's (1969) Cone of Learning

Students are expected to come to class having read about the day's topic so content coverage remains equivalent to that of lecture sections. The instructor can then minimize lecture during class to 10-15 minute periods to motivate, summarize and outline important points. Just-in-time teaching (JiTT) (Novak 2011) techniques, clicker quizzes at the start of class and/or online quizzes administered through web-based grading systems like WebAssign (Risley 1999) can hold students accountable for mastering the basics of content knowledge prior to coming to class.

SCALE-UP was not the first effort to substantially reduce formal lecture in introductory physics. Laws (1991) developed *Workshop Physics* at Dickinson College to integrate lab and lecture in calculus-based physics courses for up to twenty-four students. The technology-rich and inquiry-based curriculum involves students in making observations, doing experiments and using computers to help students build independent investigation skills. Research indicates students prefer the workshop method, demonstrate improved laboratory skills, improved performance on conceptual questions and have equivalent problem solving performance to traditional sections (Laws 1991).

Rensselaer Polytechnic Institute developed an early "studio" classroom called the "Comprehensive Unified Physics Learning Environment" (CUPLE) (Wilson 1994). Here, slightly larger classes of 30-45 students met for two hours two times per week (Cummings, Marx & Kuhl 1999) in a combined lecture and laboratory session that allowed contact hours to be reduced 60% from a traditional model without a reduction in course content. Initial gains on the Force Concept Inventory were disappointing (equivalent to typical gains in traditional courses) but improved when instructors introduced Interactive Learning Demonstrations and Cooperative Group Problem Solving (Cummings et al. 1999) into the course. Cummings et al. (1999) concluded that without research-based activities, the "use of the studio format alone does not produce improvement in conceptual learning scores as compared to those measured on average in a traditionally structured course" (p. 44).

Rensselaer Polytechnic Institute inspired Kansas State to adopt studios at their university, but in a mixed lecture-studio approach that they called "New Studio" (Sorensen, Churukian & Zollman 1996). Constrained by limited space on campus and large service teaching load for faculty in a research-oriented physics department, they retained 2 hours of lecture per week and added 2 hours of studio instruction that combines laboratory and recitation. These studios consist of up to 40 students working in teams of 4 on short, concept-oriented "lab demos" and homework problem-solving activities. Although there's still a front of the classroom, the students have moveable chairs, computer access and can use blackboards for "chalk talks". New Studio allowed Kansas State engineering classes to achieve gains "on par with those obtained through other styles of interactive instruction "Sorensen et al. 2006, p. 10-11) without requiring extra classroom space or faculty contact hours.

These studio-style predecessors influenced the development of SCALE-UP but Beichner adapted these models to accommodate large enrollment classes (at least for his first SCALE-UP implementation). In addition, SCALE-UP added a more purposeful classroom redesign to these predecessors. Students work at round tables with networked computers and access to whiteboards as public thinking spaces. Multiple display screens around the room allow students to showcase and evaluate each other's work (Beichner et al. 2007, Beichner 2008). SCALE-UP's intentional studio-space design eliminates the "front" of the room so instructors are less likely to lecture and instead engage students in activities. Equipment is accessible so students can do laboratory experiments and 10-15 minute hands-on "tangible" activities. These shorter experiments may involve making estimates and order-of-magnitude calculations as students use the predict-observe-explain model to address common misconceptions. Students also engage in more extensive, group-based laboratory work where they assume group roles and summarize findings in a formal report.

Figure 2: SCALE-UP style TEAL classroom at MIT

The Technology-Enriched Active Learning (TEAL) project at Massachusetts Institute of Technology (Dori et al. 2003, Belcher 2003) uses a SCALE-UP-style classroom and pedagogy and add two- and three- dimensional tools for visualizing electromagnetic concepts. All introductory physics courses at MIT are now taught in this format. Studies show lower failure rates and higher conceptual gains in TEAL classes (Dori & Belcher 2005) and long-term knowledge retention compared to traditional sections (Dori, Hult, Breslow & Belcher 2007).

**3) Conceptual Learning**

To address student difficulties with fundamental principles, minds-on "ponderables" are calculations or conceptual questions designed to elicit-confront-resolve student misconceptions (Beichner et al 2007). Mazur's *ConcepTests* (1997) are another way to accomplish this goal with short, multiple-choice questions designed to contain common student ideas in the answer choices (Beichner et al 2007, Dori & Belcher 2005). Mazur initially developed *Peer Instruction* to be used in large lectures. The instructor should stop every 10-15 minutes to present a *ConceptTest* to the class using the process described below:

(1) Question posed

(2) Students given time to think

(3) Students record or report individual answers

(4) Neighboring students discuss their answers

(5) Students record or report revised answers

(6) Feedback to teacher: Tally of answer

(7) Explanation of correct answer

This strategy is especially popular with instructors because it substantially increases conceptual understanding with minimal additional instructional time (Cummings et al. 1999). Even though this process is usually facilitated through the use of clickers, instructors may use personal response systems for questions in a broader domain than the specific subset of *ConcepTests* designed to target specific misconceptions.

Clicker questions are typically found in SCALE-UP classrooms, although instructors may not follow the exact protocol outlined by Mazur. The SCALE-UP literature mentions *Peer Instruction* could be used to promote conceptual understanding but does not include specific suggestions for implementing this in a studio environment. Turpen & Finkelstein's (2009) study reveals that instructors vary widely in their use of Peer Instruction and it has significant pedagogical implications. They examined use of *Peer Instruction* in introductory physics lectures at University of Colorado, Boulder. Although many professors talk about using *Peer Instruction* similarly, Turpen & Finkelstein noticed

> "large discrepancies in students' opportunities to engage in formulating and asking questions, evaluating the correctness and completeness of problem solutions, interacting with physicists, identifying themselves as sources of solutions, explanations, or answers, and communicating scientific ideas in a public arena" (2009, p.14).

How instructors implement *Peer Instruction* and clickers could contribute to the effectiveness of the SCALE-UP reform as a whole.

Modified versions of McDermott's *Tutorials in Introductory Physics* (McDermott et. al. 2002) can also be used to promote conceptual understanding in SCALE-UP (Rogers et. al. 2015). These tutorials were developed at the University of Washington to improve the recitation section that accompanied large-enrollment introductory physics courses. Two extensively-trained Teaching Assistants (TAs) supervise approximately 24 students as they do activities designed to target common misunderstandings about specific physics topics, based on extensive literature reviews and pilot testing (McDermott et. al. 1993). The tutorials take an "elicit, conflict, resolve" approach to (1) elicit students' initial thinking on the topic, (2) confront students with a situation based on logical reasoning, self-consistency or an experiment they conducted, and (3) demand students resolve these conflicts. Since the publication of these materials, the University of Maryland PER group modified them to utilize microcomputer-based laboratory equipment, re-naming it *Activity-Based Physics Tutorials* (Wittman, Steinburg & Redish 2004, Redish et al. 1997). The University of Maryland also demonstrated TAs significantly influence the students' interactions and their actions may have a significant influence on student learning outcomes (Scherr et al. 2006, Koenig et al. 2007) in the *Tutorials*. These studies indicate instructors may need guidance to facilitate the *Tutorials* (or a modified version) properly in SCALE-UP settings, since that might affect student participation and performance.

Literature on how *Tutorials* have been specifically adapted to SCALE-UP settings is limited. When piloting these *Tutorials* in the SCALE-UP classroom, Beichner (2008) suggests breaking these lessons up into 5 to 15 minute segments interspersed with brief, class-wide discussions to ensure students stay on track and allow for instructors to address difficulties before any group gets too far behind. Ithaca College used a modified version of the Tutorials in their 99-student SCALE-UP-style "Performance based physics" (PbP) implementation (Rogers et. al. 2015). When they first introduced the Tutorials into PbP algebra-based classes, students would work uninterrupted for a significant amount of time but later, they broke up tutorial work by elements of lecture or clicker questions. Despite difficulties dealing with a higher student: faculty ratio (40:1 at its lowest) and the initial lack of a dedicated course to prepare undergraduate TAs, PbP courses started to see a slightly higher normalized change on the FCI compared to before the *Tutorials* were implemented. Now, a one credit weekly course trains undergraduate TAs in pedagogy and how to facilitate the *Tutorials*.

Similar to when Studio Physics was first implemented at Rensselaer, Ithaca College found "a new technology-rich, non-traditional classroom is not sufficient to realize gains in student learning; it takes time, and deliberate and directed effort on the part of many faculty to 'dial in' the right mix of space, students, instructors and curriculum" (Rogers et al. 2015., p. 17). After a slow transition, the *Tutorials* have become a permanent fixture in Ithaca

College's PbP curriculum as a supplementary research-based strategy to promote conceptual learning.

**4) Real-world Problem Solving**

SCALE-UP implementations typically include *Real World Problem Solving* activities, adapted from *Cooperative Group Problem Solving* techniques. SCALE-UP students at NC State are trained in the GOAL problem solving protocol, inspired by Polya (1957) and encouraged to Gather Information, Organize and plan, perform the Analysis, and Learn from their efforts. Heller, Keith & Anderson (1992) found textbook problems were typically too straightforward to guarantee that students need to work together, using a problem solving protocol. To motivate higher-order problem solving beyond plug-and-chug, NC State SCALE-UP students are provided with challenging, realistic situations modified from *Context-Rich Problems* (Heller & Hollabaugh 1992), Activity-based Physics Thinking Problems (Redish 2001) or created in house. These problems are designed to read more like a story with a rationale for calculating specific quantities about real objects or events. The problems may not specify the unknown variable, may contain distracting information and/or require students to make assumptions or estimations, if necessary information is missing. These problems encourage students to apply physics concepts and principles instead of just asking, "what formula should we use?" Students are encouraged to work in groups with assigned roles working out their solutions on whiteboards which involves all group members in coming up with a solution and critically evaluating each other's work.

*Cooperative Group Problem Solving* (Heller et al. 1992, Heller & Hollabaugh 1992) was developed at the University of Minnesota for use in recitation sections that accompany large-enrollment introductory physics courses. Students are trained on an explicit five-step problem solving strategy and work together in structured groups of 3-4 students (see section C1) on context-rich problems. In well-functioning groups, students "share conceptual and procedural knowledge and argument roles, and request clarification, justification, and elaboration from one another, so a better solution emerges than could be achieved by individuals working alone" (Heller et al. 1992 p. 635). This study showed that this kind of collaboration did occur, that group solutions were better than that of any single group member and that problem-solving skills of students of all abilities improved at approximately the same rate. This resulted in more expert-like approaches than students in a traditional course. Training the students in the problem solving protocol and its relation to the goals and structure of the course reduced content coverage slightly. Implementing this effectively also required explicitly training teaching assistants about the protocol, common student misconceptions, how to grade problems and how to maintain well-functioning groups.

**5) Special considerations implementing SCALE-UP at secondary sites**

In addition to the literature on implementing aspects of SCALE-UP, some research discusses the implementation process at secondary sites. Beichner et al. (2007) outlines steps for starting implementations at secondary sites. First, faculty and departments must be willing to recognize the value of a new way of teaching. As Dori (2007) elaborates, "changing curriculum and teaching approaches calls for refreshing stakeholders' perspectives on the merit and outcomes of education as a transition from valuing knowledge acquisition to valuing knowledge construction is taking place" (p. 280). Then, the department must allow a motivated group of faculty to attempt an implementation (which is more common in larger institutions) or decide to convert the whole department (which can happen in smaller departments). This requires time to restructure courses and for faculty to build skills to be successful in this new format because "coaching student groups through activities and guiding class discussions require different skills than lecturing" (Beichner et al. 2007 p. 30). SCALE-UP instructors need to build skills beyond structuring a good lecture presentation: they must know the activity, anticipate student difficulties, guide students back on the right track and check for understanding. Students may also need guidance to change expectations about their role as a student in this reformed class (Felder & Brent 1999, Gaffney, Gaffney & Beichner 2010, Silverthorn 2006).

Beichner et al. (2007) recommends new instructors should shadow experienced faculty members and/or have weekly instructional meetings on how to teach activities, especially for non-PER (Physics Education Research) faculty who may miss some of the intricacies of research-based materials. Beichner et al. (2007) elaborates, the meetings and classroom observations of more experienced instructors can introduce "new SCALE-UP faculty… to the how and the why of SCALE-UP activities while still having the freedom to tweak them" (p. 31). This paper provides specific examples from University of Central Florida, Rochester Institute of Technology and Massachusetts Institute of Technology to demonstrate different techniques for classroom management and professional development.

Beichner et al. (2007) deemphasizes some of the logistical and administrative challenges of starting and maintaining a SCALE-UP reform but these can cause real problems at secondary sites. Notably, finding and maintaining space on campus for a studio-style room can be a huge challenge and waiting to build something new may take years (Hoellwarth &

Moelter 2011, Enderle, Southerland & Grooms 2013). For example, California Polytechnic Institute spent years improving their studio physics model, documented learning gains but only had access to one room. When other colleagues wanted to use the room for laboratories and other projects, the Studio effort was disbanded for several years (Hoellwarth & Moelter 2011). The implementation process, including advice on dealing with logistical issues, is discussed in detail for a primarily undergraduate residential college (Rogers et al. 2015) and several large research universities (Florman et al. 2014, Enderle et al. 2013, Breslow 2010).

Ithaca College gradually introduced education research-based materials (*Peer Instruction*, Washington *Tutorials*, think-pair-share, open-ended laboratories) into their course over a six-year period and found that conceptual gains did not automatically accompany the renovated room until the pedagogy was changed to match. They claim it took years after making the proposal to see results so they emphasize the importance of buy-in from the department and individuals from multiple parts of an institution to ensure sustained support throughout the process.

The University of Iowa also emphasizes the importance of collaborating with representatives across an institution to initiate a change effort. Their SCALE-UP-style reform effort came as a top-down, university-wide initiative from the Provost's office but they purposefully consulted faculty members during the classroom design process to create faculty buy-in (Florman 2014). Iowa also created extensive professional development opportunities to ensure instructor's pedagogies change to match the goals of the reformed space. To teach in their classrooms, instructors must complete professional development courses about using active and collaborative learning (Florman 2014).

Enderle et al. (2013) describe the "kinetics" of a studio physics implementation at Florida State University, exploring personal and contextual factors that facilitate and impede their effort at implementation. They claim sufficient time is the critical fundamental factor for any change effort, consistent with Rogers et al. (2015). They also found motivation levels of individual faculty do not sufficiently explain the implementation effort. Even though a core group of faculty members wanted to change the way introductory physics was taught, the studio program faced challenges from several sources that shifted over time, during the establishment of the studio physics program. The paper enumerates many tensions "stemming from operational realities of large, research universities" (p. 16) that this reform effort faced. This work confirms an organizational perspective that accounts for some of these situational barriers is required to view the implementation of SCALE-UP. Furthermore, the two-year study demonstrated how much these organizational conditions change over time, reminding us "the measurement of implementation as a 'snapshot' of what users are actually doing with respect to the innovation at one point in time" (Fullan and Pomfet 1977 p. 366) since the nature of innovation use often is constantly renegotiated with the changing circumstances of the institutional community.

**III. Useful Theoretical Constructs**

Since this thesis is grounded in exploratory, theory-building case studies, we will not impose a single theoretical framework to constrain our data analysis. However, we will review what we know and introduce several useful theoretical constructs to guide our thinking.

**A. Sense-making Framework**

Spillane et. al. (2000) provides a sense-making framework that explains many reasons implementers make modifications, including personal preference, situational constraints, social influences and how they make sense of the reform. Grounded in individual and situated cognition, this framework describes how the disseminator's framing of information can affect how an instructor receives information and subsequently perceives the reform (Spillane 2000). This interpretation can be further affected by the instructor's preexisting knowledge (Cohen & Weiss 1993), beliefs, experiences and current situation including organizational and community history (Lin 2000; Yanow 1996) and interaction in formal and informal networks (Coburn 2001).

Since researchers and instructors have different values and backgrounds, this can complicate knowledge transfer and impede utilization (Henderson & Dancy 2008, Spillane, Reiser, Reimer 2002, Beyer & Trice 1982). Agents cannot simply communicate the policy and expect immediate understanding. Instructors need time to interpret the reform and clarify implications for their behavior within their existing cognitive structures, their situation and the policy signals.

The first element of the framework applies to how individuals comprehend and make sense of innovation. In a traditional "one-size-fits-all" dissemination model, an implementer's modifications of policy can be criticized as uninformed attempts at innovation or condemnable misinterpretations. Yet, in many cases, agents faithfully attempt to replicate reforms but fail because prior beliefs can interfere with their ability to implement the reform as designed. As Cohen and Weiss wrote, "when research is used in policy making, it is mediated through users' earlier knowledge, with the policy message 'supplementing' rather than 'supplanting' teachers' earlier practice" (1993, p. 227). The interference of individual cognition can cause people to interpret the same message in different ways, to falsely perceive new ideas as familiar (and eliminate the need for change) or to miss deeper relationships because of superficial features (Spillane et al. 2002). Thus, individual sense making for learning new instructional approaches involves more than simple memorization; it may require restructuring a complex of existing theories about what it means to teach and learn within a discipline. Usually this means that implementers need extended exposure to develop a deep understand of reform; Chapter 4 investigates how initiator's ideas about the SCALE-UP reform affect their curriculum development efforts.

Implementation practice is not simply a function of an individual agent's ability and skill since the surrounding situation and social interactions can impact implementation (Greeno 1998). Individuals make sense of their world in the context of "thought communities" (such as professions, nations, political parties, religions, and organizations) (Resnick 1991; Zerubavel 2000) that situate their sense-making. In the second component of our framework, we consider how organizational and historical context, formal and informal communities and communal values and emotions affect sense making. Knowledge is emergent from the interactions of the participants in a given setting as individuals learn from and watch one another (Campione & Brown 1990; Brown, Collins & Duguid 1989), similar to the "clarification" stage mentioned by Rogers' (2003) Innovation of Organizations framework. Because of this, this work (especially in Chapters 2 and 3) attempts to track the source of information about the SCALE-UP reform.

The final component of this framework investigates how developers present the policy. Policymakers need to represent ideas about instruction in ways that enable sense making, including concrete examples grounded in underlying theory. In order for implementers to perceive a need for change, policy makers must create a sense of dissonance in which agents see problems with current instruction so they are willing to fundamentally change practice, which is what Southerland et. al. (2011) calls “pedagogical discontentment.” Once agents recognize problems with existing methods, they more willingly restructure existing beliefs to make room for the new idea. Cohen & Hill (2000) found policy is more likely to influence teaching when teachers' opportunities to learn are extended over time, grounded in the pedagogy presented, and are connected to several dimensions of teaching.

**B. Adoption-Innovation Continuum**

This project seeks to understand the implementation process and enacted use of research-based pedagogies, using SCALE-UP as an example. We want to examine the implementation process, “what an implementation consists of in practice” (Fullan and Pomfret 1977 p. 336) so the adoption-invention continuum helps us identify which elements of a reform are modified and directly adopted. This is important since current models of diffusion reveal few reforms are implemented as designed. For example, Henderson & Dancy (2008) demonstrate that new users often adapt and reinvent instructional tools to fit their needs, adding new characteristics that distinguish it from its planned or intended use.

When looking at enacted classroom use, one must recognize the role of both the developer of original innovation and the instructor putting it into practice. We do not want an “adoption model” that assumes participating instructors implement the reform more or less as prescribed (Ellsworth 2000, Fullan 2002) since this would blind us to how instructors independently innovate in their classrooms (Henderson 2005). Furthermore, adaption should not be ignored since it can have positive benefits including increasing the chances of sustained change (Rogers 2003, O'Loughlin et al. 1998). This study plans to take a neutral stance on adaptation, especially since SCALE-UP does not have a specified curriculum and therefore cannot be adopted without input from the instructor.

Henderson and Dancy (2008) propose an adoption-invention continuum to investigate how substantially physics faculty members modify reforms. As seen in Figure 2, the continuum ranges from an *adoption pole* where the external agent develops all materials to be implemented as is to an *invention pole* where the instructor controls the development with minimal external influence.

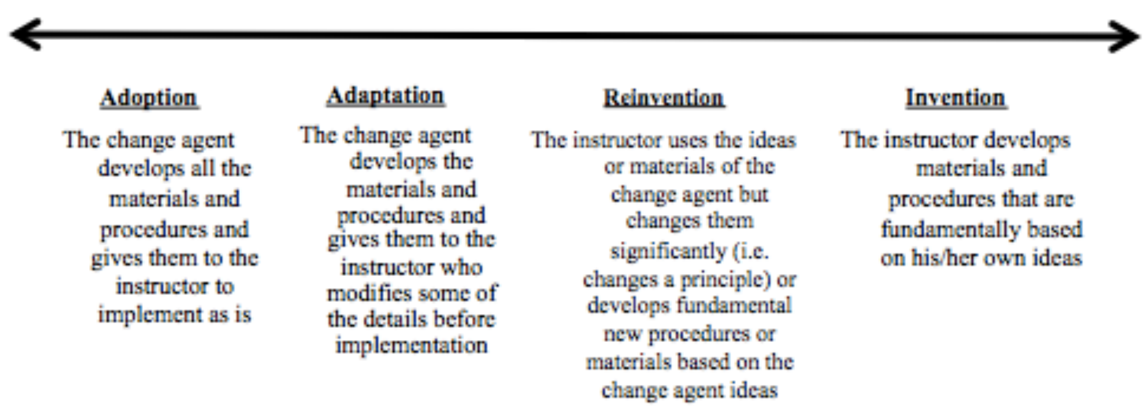


Figure 3: Adoption-invention continuum, proposed by Henderson and Dancy (2008)

To see where on this continuum most enacted undergraduate physics curricula fell, Henderson and Dancy (2008) asked five faculty members to describe their use of research-based strategies, including what changes they made and why. Even though these faculty members tended to agree with education research on the problem they wanted to solve in their classroom, most (70%) of the changes the instructors made fell on the reinvention/invention side of the continuum. Instructors often did not implement the complete research-based solution and sometimes made fundamental modifications inconsistent with underlying research. This happened even though these instructors were "likely physics education research users" who wanted to improve their teaching with new techniques.

Henderson and Dancy (2008) also found most faculty members believed educational researchers expected them to use models as prescribed. As a result, they often re-invent the curricula alone without sharing the successes and failures of their modifications amongst other users. Even when the developer of SCALE-UP tried to get implementers to share their resources on the SCALE-UP wiki (http://scaleup.ncsu.edu), instructors were hesitant, claiming "the resources were not ready" or "would not be helpful for others" *(personal communication 3/3/2015)*. Hiding information from other users deprives other secondary implementers and the research community of valuable information.

Instead of perpetuating the idea that reforms should only be used as prescribed, this study views adaptation as an inevitable (and potentially productive) part of the implementation process. Sharing modifications users made will help other sites know which aspects of the reform can transfer and gain recommendations for context-dependent modifications. This continuum helps quantify change.

## IV. Overview of Dissertation

### A. Purpose of Project

This study responds to a call for a close examination of educational change and attempts to describe the highly personal, dynamic and interactive process that unfolds as institutions adopt complex educational innovations in non-trivial, context-dependent situations. The goal is to use case studies and a nationwide census to develop an evidence-based theory of diffusion that allows for adaptation by examining enacted use of SCALE-UP in natural instructional environments.

We hope we can use this reform, which has achieved more success than others, to guide general implementation efforts. By conducting case studies of relatively successful secondary sites, we can identify what adaptations sites tend to make, which may have implications for how reform developers should support them. Ideally, this will allow secondary sites to take advantage of flexibility of form without sacrificing function. Studying how people understand and implement the SCALE-UP reform will have important implications for framing and spreading research-based reforms, for both reform developers and policy-makers.

### B. Overarching Research Questions:

1. How do implementers learn about SCALE-UP? What motivates the implementation?

2. What factors affect the initial form of a SCALE-UP implementation?

3.  During use, how do users further modify the reform to fit their local setting? Why do they make changes?

4. How do sites achieve sustained use of the reform?

## C.  Overarching Methodological Approach

This research project was undertaken to promote successful dissemination of SCALE-UP and other innovations, a goal that requires strong linkage between theory and practice. Interest in the dissemination of educational reforms is still relatively new and existing literature exposes holes in the current research and calls for more evidence-based studies (Fairweather 2008, Seymour 2002, Henderson et al. 2011).   To improve our scholarly understanding of the dynamics of diffusion of innovations, using case studies is the only appropriate methodological approach to capture real-life complexity.  The internal and external environments of each institution are unavoidably unique in ways that cannot be accounted for by empirical studies that eliminate distinct contextual factors.  Case studies and qualitative data are needed to offer insights into complex social processes that quantitative data cannot reveal, especially since the literature lacks unified, viable theory and related empirical evidence.

Yin (1994) defines case studies as rich, empirical descriptions of particular instances of a phenomenon within its real-life context when the boundaries between the phenomenon and context are not clearly evident.  Case studies can provide description (Kidder 1982), test theory (Pinfield 1986, Anderson 1983) or generate theory (ex Gersick 1988, Harris & Sutton 1986).  Since dissemination of educational innovations still does not have a satisfactory theoretical framework, these studies fall into the final category. As Eisenhardt and Graebner (2007) explain,

> "The central notion is to use cases as the basis from which to develop theory inductively. The theory is emergent in the sense that it is situated in and developed by recognizing patterns of relationships among constructs within and across cases *and* their underlying logical arguments" (p. 25). *[italics original]*

As mentioned in the literature review, an awareness of existing theoretical constructs may illuminate some of our interpretation without constraining the analysis to testing hypothetical relationships.

When done well, the likelihood of validity is high using the theory-building approach because the underlying hypotheses have repeatedly undergone verification and because of the close tie with evidence. Critics of case study research claim theories are limited by the investigator's pre-conceptions but that can be avoided with a divergent approach to data analysis. By constantly juxtaposing conflicting realities by iteratively comparing cases, the case study process has more potential to unfreeze thinking with less researcher bias than incremental studies (Eisenhardt 1989).

This study, as with most case studies, combine the use of qualitative and quantitative methods. Data are collected through a large-scale survey, classroom observations, documents and course artifacts and semi-structured interviews with faculty members and administrators. At each institution, numerous interviewees with varying experiences with the reform to learn about implementation from diverse perspectives. Whenever possible, we interviewed people who were involved in reform implementation at different times to mitigate retrospective sense-making by combining it with real-time insights (Leonard-Barton

1990). In Chapter 4, we spoke to the same people multiple times over a span of several years to verify previous comments.

Having both qualitative and quantitative data provides a synergy of additional depth and understanding of underlying relationships. Systematic data helps to build foundational relationship but anecdotal data is needed to explain complex relationships, "Theory building seems to require rich description, the richness that comes from anecdote. We uncover all kinds of relationships in our hard data, but it is only through the use of this soft data that we are able to explain them" (Mintzberg 1979 p. 587).

In summary, because of the lack of unified theory surrounding the innovation implementation process of educational at institutions of higher education, the research aim of this study was to form evidence-based hypotheses by understanding implementation in multiple settings. A review of literature led to the formulation of a tentative theoretical conception of the implementation process in organizations to help identify factors that might affect this process. As will be seen in subsequent chapters, data was collected and analyzed in a way to posit and investigate the relationship between factors. This approach aims to lead to an empirically-grounded innovation dissemination theory that can provide guidance for researchers and policymakers.

More detailed discussions of the methods used for particular studies are described in subsequent chapters.

### D. Overview of Dissertation

I briefly describe the structure of this dissertation and the particular studies that will be examined in further detail within this work. This work combines three stand-alone papers that portray a growing understanding of dissemination of innovations, through the example of SCALE-UP. Throughout these coming chapters, conceptual framing and additional literature will be brought in as they relate to specific studies.

In Chapter 2 (which addresses all four research questions), we follow the evolving use of SCALE-UP-style reform through three generations of implementation at two domestic and one international site. Interviews and class observations were used to examine how classroom, departmental, institutional and cultural factors have caused the reform to proceed through an iterative version of Rogers' (2003) "Innovation in Organizations" model. 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 shifted pedagogy toward traditional instruction, potentially decreasing the reform's intended benefits. This exploratory case study revealed that reinvention is a critical part of the process and deserves further examination in subsequent chapters.

In Chapter 3 (which primarily addresses research questions 1 and 3), we report the results of a web survey used to develop a census of instructors who have been influenced by SCALE-UP. The survey identified that SCALE-UP style instruction is currently used in over a dozen disciplines at a minimum of 314 departments in at least 189 higher education institutions in 21 countries. Many more respondents learned about SCALE-UP via interpersonal channels, such as talks/workshops and colleagues, than via mass media channels, such as the Internet and publications. We estimate the dissemination of SCALE-UP in physics is at the tipping point between adoption by adventurous early users and the more mainstream majority. Implementers demonstrate pedagogical and structural variation in their use of SCALE-UP. These results suggest that leveraging interpersonal networks can help accelerate dissemination of educational innovations and should be used more for bringing about change. Since SCALE-UP may be nearing a tipping point within the discipline of physics now may be the time to modify change strategies to appeal to more typical faculty rather than the early adopters. For SCALE-UP, having the structural commitment of a specialized classroom may improve the likelihood of continued use at an institution.

While the survey results primarily focus on the initiation part of the implementation process, Chapter 4 focuses more on the implementation and reinvention process (strongly addressing research questions 2, 3 and 4), as people develop a curriculum to accompany the reform. Case studies were chosen to be five "successful" sites with 100% usage in the introductory physics sequence. Exploring how these successful secondary sites managed this adaption process will have implications for how secondary users can tailor their own reinvention process to customize their reform to fit their local setting. Revealing how these sites navigate curricular development, physics users will have a practical guide to aid adoption while researchers have theoretical recommendations for improving dissemination. The conclusion will revisit the overarching research questions, provide practical implications and identify directions for future work.

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## CHAPTER 2: Factors Underlying the Adoption and Adaption of a University Physics Reform over Three Generations of Implementation

### 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.

### 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 RensselaerPolytechnic 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.

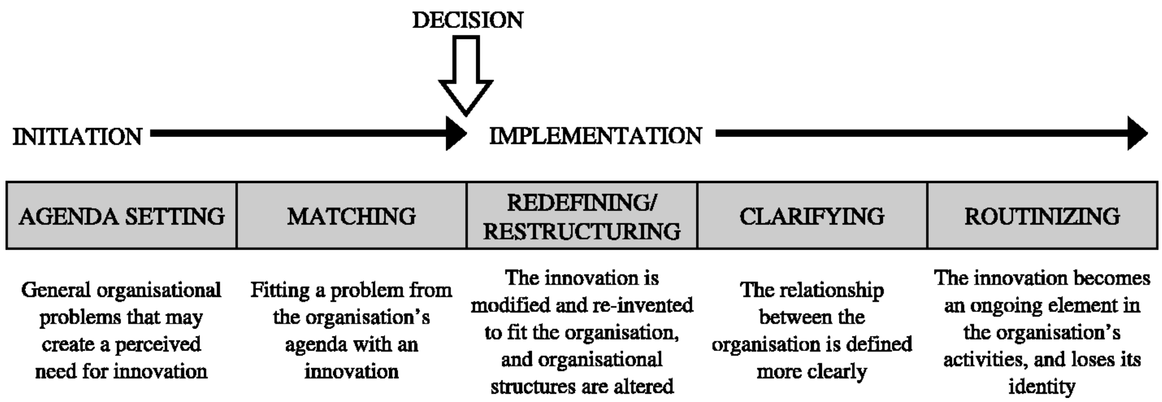


Figure 1: Innovations in Organizations (Rogers, 2003, p. 421)

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 reinvent 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 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?

RQ3: How do sites factors clarify and routinize the 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.

Table 1: Description of Class 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. |
| Presentations | Unidirectional dissemination of content from students to the instructor and 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. |

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 1: Initiation (Agenda-setting and matching)**

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 populations.

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.

**Results 2: Redefining/restructuring**

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), 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. 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.

**Results 3: Clarifying/rountintizing**

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.

<u>How do the current implementations compare?</u>

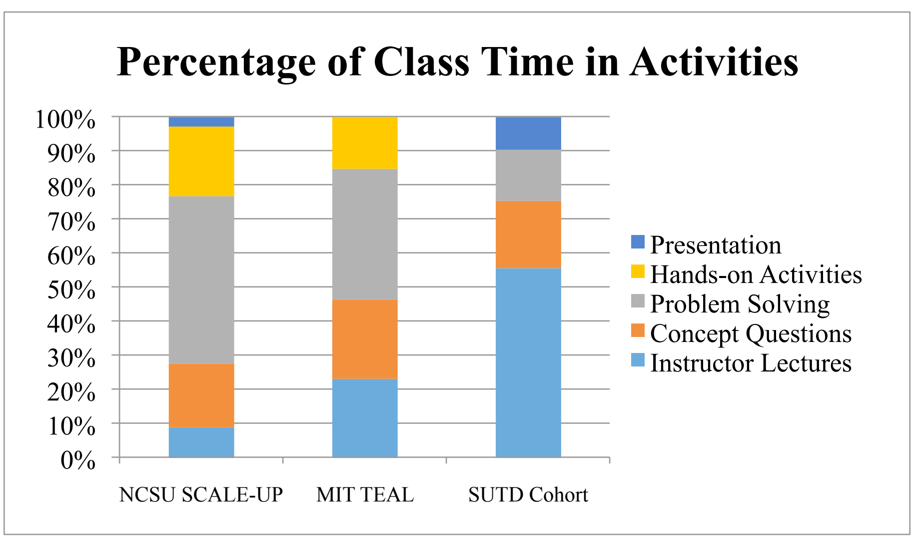


Figure 3: Percentage of class time spent in various instructional activities averaged over a week of observations.

**Results/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.

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**CHAPTER 3: Diffusion of research-based instructional strategies: The case of SCALE-UP**

**Abstract**

Background: Many innovative teaching strategies have been developed under the assumption that documenting successful student learning outcomes at the development site is enough to spread the innovation successfully to secondary sites. Since this 'show them and they will adopt' model has yet to produce the desired large-scale transformation, this study examines one innovative teaching strategy that has demonstrated success in spreading. This instructional strategy, Student-Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP), modifies both the pedagogy and classroom design to maximize interaction and activity-based learning. A web survey was used to develop a census of instructors who have been influenced by SCALE-UP.

Results: SCALE-UP, which started in large enrollment university physics, has spread widely across disciplines and institutions. The survey identified that SCALE-UP style instruction is currently used in over a dozen disciplines at a minimum of 314 departments in at least 189 higher education institutions in 21 countries. Many more respondents indicated learning about SCALE-UP via interpersonal channels, such as talks/workshops and colleagues, than via mass media channels, such as the Internet and publications. We estimate the dissemination of SCALE-UP in physics may be at the tipping point between adoption by adventurous early users and the more mainstream majority. Implementers demonstrate pedagogical and structural variation in their use of SCALE-UP.

Conclusions: Leveraging interpersonal networks can help accelerate dissemination of educational innovations and should be used more prominently in change strategies. Since

SCALE-UP may be nearing a tipping point within the discipline of physics, now may be the time to modify change strategies to appeal to more typical faculty rather than the early adopters. This may include using successful secondary implementers as like-minded intermediaries to reach out to people considering the use of the innovation in different institutional settings for more practical and relatable advice. For SCALE-UP, having a specialized classroom may improve the likelihood of continued use at an institution. We also hypothesize that having a special classroom may start departmental conversations about innovative teaching and may make instructors less likely to revert back to traditional methods.

**Background**

Much time, money, and effort has been spent in developing innovative teaching pedagogies, documenting their effectiveness, and disseminating the results. Although these efforts have had some impact on teaching practices, there has been no systematic movement of college instruction at large research institutions toward consistency with research-based best practices (e.g., Wieman et al. 2010, Dancy and Henderson 2010, Handelsman et al. 2004, Henderson and Dancy 2009a, National Research Council 2003, Redish 2003). Reformers typically develop a new pedagogy at their institution and then disseminate the new instructional model through talks, workshops, and papers. This development and dissemination model of reform assumes that telling faculty about good teaching ideas will lead faculty to integrate these ideas into their teaching practices. However, this intuitive 'show them and they will adopt' model has yet to produce desired large-scale transformations, indicating that a more robust research-based model of change is needed

(Fairweather 2008; Seymour 2001; Henderson et al. 2011).

In addition to lacking an overall model of how new teaching ideas spread, very few studies document what happens when secondary sites attempt implementations.

Usually, an individual or small group develops a reformed pedagogy and disseminates it for use in many different educational settings. However, the unique combination of students, instructors, and structures at each location complicate transitions to other sites (Finkelstein and Pollock 2005; Pollock and Finkelstein 2007; Sabella and Bowen 2003; Saul and Redish 1997; Sharma et al. 2010). Furthermore, secondary implementers often lack the grant funding, a project team, faculty release time, and education experts that contributed to success at the development site. As the most common type of site, secondary implementations deserve close attention especially from reform developers who want their innovative teaching strategies to spread successfully.

These sites also deserve more attention because secondary implementers can make significant modifications that can comprise the intended results of the reform. Instructors often adapt reform, and often, these changes are in the direction of traditional instruction (Dancy and Henderson 2010; Henderson 2005, 2008; Henderson and Dancy 2009a; Henderson and Dancy 2009b). Without investigating how the implementation has been adapted, 'it may be difficult to interpret learning outcomes and to relate these to possible determinants' (Fullan and Pomfret 1977, p. 338). This is especially important for less successful sites, since lower-than-expected gains can disappoint and frustrate adopters. For example, researchers studying learning gains at a secondary site found that improvements in student learning after using interactive lecture demonstrations were 'nowhere near' those claimed by developers (Sharma et al. 2010). The researchers were unable to identify the reasons for these disappointing results. To understand why some sites are more successful than others, it is important to monitor the details of implementation, not just the reform they claim to be using.

This project examines how the Student-Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP) (Beichner et al. 2007; Beichner 2008) reform spread and how secondary sites implement the reform. Our intent is that this study will (1) contribute to a research-based understanding about how reforms spread, (2) identify typical modifications made in secondary implementations, and (3) develop recommendations to guide curriculum developers toward more successful dissemination. Although this study is focused on the SCALE-UP instructional strategy, we believe that the results are relevant more widely to instructional change in higher education.

What is SCALE-UP and why examine it for this study?

Dr. Robert Beichner developed SCALE-UP for large enrollment university physics courses at North Carolina State University in 1997. As we have found in this study, this reformed pedagogy and classroom environment has successfully crossed disciplines and continents and is currently used in at least 314 departments at 189 higher education institutions worldwide. This study closely examines the dissemination and implementation of this specific instructional strategy in order to develop general trends that may help other educational innovations become successful, like SCALE-UP.

SCALE-UP is a radical reform. In SCALE-UP, instructors modify their pedagogy to minimize lecture and make major physical changes to the classroom arrangement. When implemented well, radical reforms like SCALE-UP have been shown to lead to higher learning outcomes than more modest reforms (Redish 2003). SCALE-UP changes the instructional methodology and course structure by integrating lab-lecture recitation and redesigning the classroom to a studio environment. Round or D-shaped tables, whiteboards on walls, and technology with projection capabilities facilitate collaboration and sharing of student work. No obvious 'front' of the room encourages instructors to minimize lecture, circulate and engage teams of students in Socratic dialogs, real-world problem solving, and technology-rich activities. Reforms that involve structural changes, like SCALE-UP, require departmental buy-in and thus may be harder to adopt. We hypothesize that this investment in structural changes may also decrease the chance of discontinuation once the reform is in effect.

SCALE-UP presents an interesting case study for multiple reasons. First, SCALE-UP is not discipline or curriculum specific. The large number of secondary sites allows us to identify discipline-based differences and investigate the ways people use the reform in an assortment of institutional settings. Additionally, information about SCALE-UP has been successfully disseminated through a variety of formal and informal means, both by the developer and by other sites. Finally, since so many sites have adopted SCALE-UP at different times over the past two decades, we can examine sites at different implementation stages and ones that have achieved different degrees of spread within the universities. 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 et al. 2003). To spread these benefits successfully, it is extremely important to understand how secondary implementations of highly innovative curricula, like SCALE-UP, work. By examining why they are adopted, if/how modifications adjust the reform to their unique context, and the impact these modifications have on student learning, we can promote the diffusion of effective and sustained reforms.

**Literature review**

This section briefly summarizes several claims from the diffusion of implementations (DOI) literature and innovative teaching research that are relevant to this study. According to Rogers (2003), diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system. DOI theory describes this process, where socially constructed information about a new idea is communicated from person to person. Rogers (2003) developed these ideas after analyzing a wide variety of innovations - from farmers using a new hybrid seed to physicians utilizing a new drug to corporations incorporating a new technology - and the theory also applies to educational innovations (Nutley et al. 2002; Berman and McLaughlin 1978; Green and Johnson 1996). We chose this framework since it explores the dynamic process between communication and innovation implementation in a social context. We hope it will help us understand how information about SCALE-UP is communicated and how this reform is adopted and utilized and changes behavior at secondary sites. This framework does not assume a simple, linear progression from product development to adoption and thus allows us to explore the stages of spread in detail. According to the DOI theory, the spread of information about an innovation and the implementation process is influenced by four factors: innovation attributes, communication channels, adopter characteristics, and adaptation. The literature claims that the following factors influence the spread of information about an innovation and its implementation at a secondary site.

<u>Innovation attributes</u>

Rogers (2003) identified several innovation attributes that aid rapid diffusion. We consider these here, in relation to SCALE-UP. First, successful innovations are perceived to have a significant relative advantage over current alternatives. As previously mentioned, as a radical reform, SCALE-UP has been demonstrated to dramatically improve student learning (Beichner et al. 2007; Beichner et al. 2000; Beichner 2008). Thus, we believe that departments seeking to substantially change their educational techniques will perceive SCALE-UP as a way to significantly change educational outcomes. Secondly, users are more likely to adopt innovations with high-perceived compatibility with past practices, current values, and existing needs. SCALE-UP is unlikely to be compatible with past practices in most traditional departments. Thus, it seems like that more innovative departments, who have been trialing more interactive educational pedagogies, may be among the first to adopt. Next, users are more likely to adopt low complexity innovations that can be readily understood and easily implemented. Although SCALE-UP requires many structural changes to implement, the underlying principles are relatively straightforward and intuitive to understand. Adopting a pedagogy and classroom space to support active and collaborative learning (Beichner 2008) seems sensible to most users, which can aid the spread of SCALE-UP. Fourth, users are more likely to adopt innovations with high trialability, where new ideas can be tried out at a low cost before it is completely adopted. Since SCALE-UP requires modifying the classroom space and often the schedule (to combine the lecture, lab, and recitation sections of a course), a high-fidelity

SCALE-UP implementation is not cheap or easy to trial on a temporary basis. However, we believe that once departments make the investment, observability, the fifth characteristic of successful reforms, significantly facilitates the success of SCALE-UP. Observability measures the degree with which others can view the use and benefits of the innovation, thus stimulating further uptake by others. Since a SCALE-UP classroom looks so different from a traditional lecture hall, we believe that observability will be a key factor that promotes the spread of SCALE-UP within and between institutions.

In addition to these classic innovation characteristics identified by Rogers, other researchers have identified potentially important characteristics, such as adaptability, centrality to the day-to-day work of the organization, and the minimal requirement for additional visible resources (Wolfe 1994). For our study, another aspect of SCALE-UP is that a department, not an individual, is often the adopting unit. Since SCALE-UP requires such a dramatic restructuring and often a financial investment, the decision to adopt is often made at the department level. Thus, instead of analyzing the diffusion of ideas among individuals, we chose to look at the spread of ideas among departments and elect to use that grain size for the majority our study. This choice is supported by other research on innovations in organizations (Katz 1962; Nutley et al. 2002; Lewin 1947; Wildemuth 1992; Zaltman et al. 1973) but can introduce complicating factors since the strength of evidence on whether adoption will lead to improved effectiveness does not seem to be the main factor influencing adoption decisions (Stocking 1985; Westphal et al. 1997) but instead depend more on current fads and fashions, especially during times of high uncertainty (DiMaggio and Powell 1983).

<u>Communication channels</u>

According to DOI, the communication channels through which the message spreads also influence the rate of adoption. A distinction is generally made between interpersonal, where messages originate from local sources, and mass media channels, where messages comes from distant sources (Rogers 2003). Disseminating educational innovations via 'mass market channels' (Rogers 2003) such as websites, conference presentations, and journal publications can raise awareness of an innovation. However, to move potential users from learning something new to changing their practices, interpersonal channels are often more influential when it comes to behavior (Borrego et al. 2010; Rogers 2003).

Furthermore, intermediaries between the innovators (curriculum developers in our case) and the broad mass of potential adopters are often important communication channels between these dissimilar groups. These include opinion leaders who adopt the innovation themselves early on and tend to be more innovative and of a higher status than their near peers. This helps more conservative middle and late adopters overcome caution about the risks involved with adopter. Secondly, intermediary change agents can work proactively to expedite and widen innovation usage by reducing barriers, persuading adopters, and supporting adoption decisions. These leaders bridge the divide between technical experts and clients so they can mediate interactions and work effectively with both groups. The credibility of the change agent and level of contact with the change agent are both positively related to the decision to adopt (Rogers 2003; Colemen et al. 1966).

In this project, we investigate how people learned about SCALE-UP. In addition to mass market channels, we probe social connections - which theory indicates are essential to the reform process - through a SCALE-UP census. Our survey identifies users, asks how they learned about the reform, and examines whether the communication method impacts their use of the reform. We hypothesize that mass-market channels may be important early on but that interpersonal channels accelerate the spread of SCALE-UP.

Adopter characteristics

Typically, an innovation needs a critical mass of adopters before it can achieve a self-sustaining spread. For successful dissemination, the rate of adoption typically follows an S-shaped curve like that shown in Figure 1, where the rate of adoption 'takes off' once interpersonal networks become activated in spreading the idea from peer to peer within a system. The adoption rate begins to level off after half of the social system uses it, since non-knowers become scarce.

Diffusion of innovation theory allows us to categorize adopters' characteristics based on their tendencies to adopt (Rogers 2003; Moore 2002). Although the characteristics and S-curve percentages are generalizations, developers should pay attention to this curve and ideally target each group with a different diffusion strategy (Green and Johnson 1996). As shown in Figure 1, Rogers describes the first 2.5% of adopters as innovators. Innovators tend to be social, willing to take risks, and closely connected to scientific sources. Early adopters, the next group, are also educated, have a high social status, and typically have the highest opinion leadership of the adopter groups. According to Rogers, innovators and early adopters both respond to the newness of an idea and are not deterred by things that may not work perfectly. However, the early majority are much more conservative and cautious, which is when change agents and opinion leaders become important in spreading the idea amidst this population. The implication is that change initiatives should change their strategies in accordance with changing adopter characteristics if they want their innovation to spread to the mainstream. Once an innovation has reached the innovators and early adopters (somewhere around 16% adoption), the marketing strategy needs to change to appeal to the more hesitant early majority (Moore 2002; Rogers 2003).

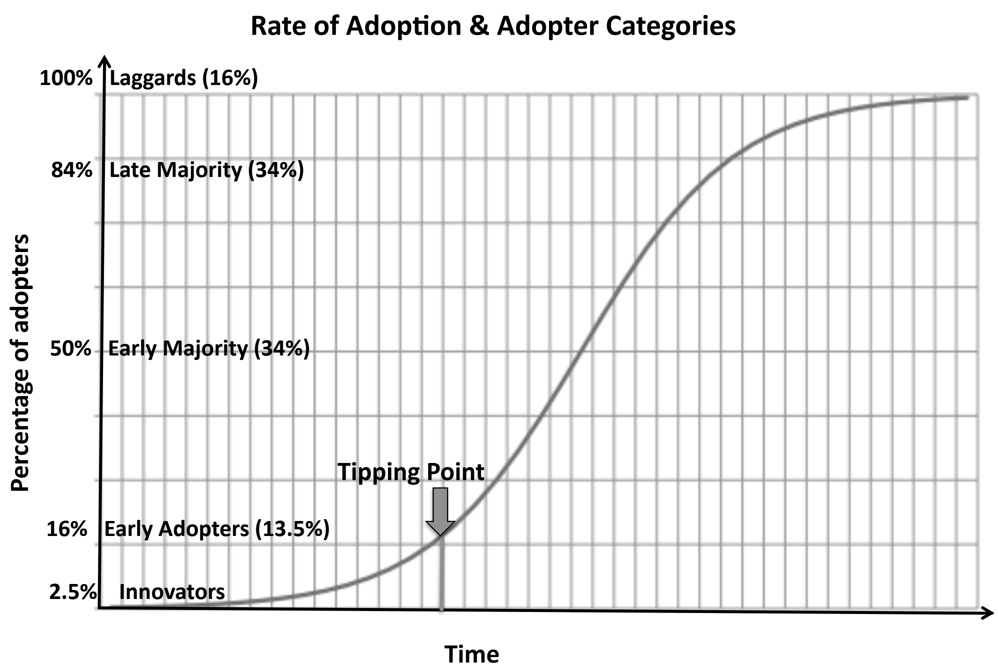


Figure 1: Rate of Adoption & Adopter Categories

In this project, we will compare the diffusion of SCALE-UP to the S-curve and identify how close SCALE-UP is to the 16% tipping point. If SCALE-UP passes this tipping point, dissemination may need to involve other people to convince the mainstream.

Role of adaptation

Diffusion can range on a continuum from highly centralized (top down diffusion from expert to users) with a low degree of adaptation to decentralized systems with a high degree of local adaptation (where diffusion happens through horizontal networks with a wide sharing of power and control among members).

In general, research and development agencies tend to promote a high fidelity, top-down approach and may consider reinvention as a distortion of their original technologies. Thus, historically, dissemination of reforms has taken a linear, top-down approach in the development and dissemination model, presenting faculty with a packaged ready-to-go curriculum designed for unmodified use. This model does not acknowledge the expertise of adopting faculty, who rarely want to use reforms as designed and may adapt reforms back toward traditional instruction (Hutchinson and Huberman 1994; Henderson and Dancy 2008).

On the other hand, adopters tend to think that reinvention is a desirable quality because it promotes a closer fit with their needs and studies in education. Research suggests that instructors are more open to a collaborative approach, where researchers and users exchange specialized knowledge in a mutually constructed social context. As Cohen and Ball explain, 'Teachers view themselves as independent, autonomous professionals…Even the most obedient and traditional teachers observed, enacted policies in their own ways and were proud of their contributions' (1990, p. 253).

Researchers have shown that reinvention not only increases the likelihood of adoption but also reduces the likelihood of discontinuance (Berman and Pauley 1975; Rogers 2003). However, these same educational studies also suggest that when the level of reinvention is quite high, then the desired outcomes can diminish substantially (Henderson and Dancy 2008; Penberthy and Millar 2002; Sharp and McLaughlin 1997; Silverthorn et al. 2006; Hutchinson and Huberman 1994; Berman and Pauley 1975; Berman and McLaughlin 1978).

This project identifies how instructors and departments adapt SCALE-UP, pedagogically and structurally, and examine how that relates to adoption, implementation, and sustainability. We hypothesize that a department's commitment to redesign the classroom may help reduce the tendency to revert back to traditional instruction, which can occur in educational reforms where instructors have freedom to make changes.

The literature lacks consensus regarding how to promote effective spread of complex innovations like SCALE-UP. SCALE-UP restructures the classroom environment and pedagogy in a way that often requires a formal decision by higher members of an organization. The larger adoption unit - a department in our case - for innovations like these introduce complicating factors, which means that much of the literature on individual adoption of simple, product-based innovations (for example, in educational technology) cannot be generalized (Greenhalgh et al. 2004). Since radical reforms like these have the best chance of improving student outcomes (Redish 2003), the field still needs to examine how involved innovations spread effectively. This project aims to deepen our understanding of this by using the case of SCALE-UP to study how complex research-based reforms spread, within and across institutions, including how people learn about and implement them.

Research questions

1) To what extent has SCALE-UP spread? Are these rates of spread consistent with diffusion of innovation theory?

a How many physics departments has it spread to?

b How many other disciplines has it spread to?

c How much does SCALE-UP spread within a department?

d Are these rates consistent with diffusion of innovation theory?

2) Through what communication channels does knowledge about SCALE-UP spread?

a. How do adopters learn about SCALE-UP?

b. Does the communication channel affect the way adopters use the reform?

3) How do secondary sites adapt the pedagogy and structure of SCALE-UP? How does this impact the success of the implementation?

a. How does the pedagogy and structure of enacted implementations vary by user status? Discipline?

b. How does structural variation (classroom type) relate to the use of active learning pedagogies?

**Methods**

Data were collected via a web survey of faculty likely to be aware of SCALE-UP. This section will first describe the survey design and then discuss the survey implementation.

Survey design: The survey questions were designed to address the research questions and census SCALE-UP use internationally. Since we were exploring a respondent's interactions with and interpretations of SCALE-UP specifically, we were not able to use the preexisting survey instruments.

The research team reviewed the literature and created a list of potential survey questions, based on past research and personal experience. For the questions designed to measure fidelity to the original reform we had, Beichner, the developer of SCALE-UP, describe his model and share what he has observed that is happening at other sites. This helped us create question options that captured subtle differences. The survey included multiple choice, multiple select, and free response questions that allowed respondents to describe their implementation. The survey is included in Appendix B.

The web-based survey contained three main parts: (1) questions about the respondent's personal use of SCALEUP at their institution (demographic information, instructional practices, self-described user status), (2) questions about SCALE-UP use in the respondent's department/ institution (physical room set-up, contact person, duration of use and percentage of instructors using SCALE-UP I the department, other SCALE-UP departments at the institution), (3) questions about the spread of SCALE-UP(How did you learn about SCALE-UP?  Whom did you tell about SCALE-UP?). Additional survey details and specific questions will be discussed as needed in the 'Results and discussion' section. Branching was used so the survey would be appropriate for instructors, administrators, as well as past/potential/current users.

In order to improve the quality of data collected, the survey triangulated responses in two ways. First, the survey contained some questions that were designed to get at the same construct, but in different ways. Responses to these questions were compared during analysis. The second type of triangulation was that in many cases, we had multiple respondents in the same institution and department. Thus, we were able to determine the consistency of responses for questions relating to the department and institution.

We pilot tested the preliminary survey with three faculty members from three different universities and two different disciplines. After they completed the survey on their own, we interviewed these individuals and used their feedback to improve the clarity and appropriateness of the questions. After that, we distributed the survey to a small sample of 50 recipients to verify smooth administration of the instrument before inviting additional respondents.

Survey implementation: The goal of the survey was to develop a census of SCALE-UP use at higher education institutions. Current, past, or potential users of SCALE-UP style instruction were the target population of the survey. We did not wish to sample from this population, but rather to survey the entire population. This, of course, is an unreachable goal. We used several techniques in the survey implementation to identify respondents in our efforts to approach this goal of a SCALE-UP census.

First, surveys were sent to all current members of the SCALE-UP wiki database (http://scaleup.ncsu.edu/). The SCALE-UP wiki is a password-protected collection of resources about implementing SCALE-UP style instruction.

At the time of the survey, there were 1,321 members of the wiki, virtually all of whom had contacted Beichner requesting information about SCALE-UP. In addition, we created an open survey link. This open link was distributed via relevant listservs (e.g., physics modeling, Arizona State University science faculty). Individuals were encouraged to share the link with other instructors in their discipline.

Finally, snowball sampling was used to identify additional respondents. During the survey, the respondents were asked from whom they had learned about SCALE-UP and whom they told about SCALE-UP, including a contact person in their department. Survey invitations were sent to any people listed whom we had not previously contacted.

To ensure the thoroughness of the sample, we conducted internet searches to identify additional institutions using SCALE-UP instruction. Of the top 30 institutions returned by an Internet search, all but two of these sites were already in the database and had already been contacted for the survey. This provides some evidence that our list of survey respondents was reasonably complete. Note that we do expect that not all SCALE-UP implementations publicize their use of the innovation with a website.

Approximately 1,300 survey invitations were sent in rounds between December 2012 and August 2013. The email invitation described the goal of the survey: conducting a census of people using SCALE-UP style instruction.

Thus, people who filled out the survey associated themselves with SCALE-UP use, or at least acknowledged that the reform influenced their teaching. Three reminders were sent to non-respondents, and individuals could elect to be removed from the list if they thought the survey was irrelevant. In the end, 812 surveys were started with 84% of these respondents completing the entire survey. For this study, responses were only retained from respondents at American higher education institutions, leaving a sample of 659, a better than 50% response rate. SCALE-UP originated in the US so we chose to focus on universities with a similar cultural context. In other countries, different social and cultural norms could complicate the way SCALE-UP was implemented and we wanted to remove cultural factors from adding an additional variable to the study. Furthermore, since 84% of respondents came from the US, we decided to focus on getting a detailed understanding of domestic implementations.

We analyzed completed responses for each question answered, even for incomplete surveys. For some results, we used the department as the unit of analysis, combining responses from multiple respondents in a single department to form a picture of implementation at this level. When responses differed, we either went with the majority of respondents (if there was a majority that answered in the same way) or took an average response if there was not a majority.

Limitations of the study

Using a survey as a mode of data collection inevitably introduces some limitations to our study. Survey methods rely on self-report, which has been critiqued on various grounds including limited internal and ecological validity (Podsakoff and Organ 1986; Stone et al. 1999). In the field of higher education, researchers have expressed concerns about the ability of instructors to accurately report classroom happenings accurately in sufficient detail (e.g., Dancy and Henderson 2010; Ebert-May et al. 2011). Aware of these challenges, the survey did not ask respondents to provide a cohesive picture of all their teaching practices, just the key aspects that relate specifically to SCALE-UP.

The questions were designed to be as general and direct as possible in an effort to avoid misrepresentations. For example, instructors were asked to select whether certain equipment was present in their classroom (whiteboards on walls, computers for small groups to access, projection capability) or estimate the percentage of time they spent lecturing, students spent problem solving, etc. (1% to 25%, 25% to 50%, 50% to 75%, 75% to 100%).

When there were multiple respondents from a department, we checked the responses on relevant questions against each other for agreement (for example, percentage of people in a department using SCALE-UP to teach introductory classes, years SCALE-UP has been used at a department, structural equipment in classroom). Having multiple respondents report similar descriptions of how SCALE-UP is used in their departments helps reduce some concerns about self-report. In some cases, there were up to five instructors from the same department whereas other departments only had one respondent.

The questions analyzed at the departmental level, as all questions on the survey, were as general and direct as possible. Significant disagreements among faculty within a department were rare. Another limitation of our study is that we used a broad definition of SCALE-UP 'users' because almost all faculty members make modifications and have difficulties characterizing their use. Early in the survey, respondents were asked to describe their user status of SCALE-UP style instruction, which we defined in the survey as 'SCALE-UP style instruction is characterized by the promotion of social interactions among students and instructors, use of engaging activities during class along with a substantial reduction in lecturing, and a focus on developing conceptual understanding and thinking skills. By having students attempt difficult tasks in a supportive environment, they experience the application of their new knowledge. Students have opportunities to practice teamsmanship, presentation of their own work, and evaluation of the work of others.

Classroom furnishings are specifically chosen and/or arranged to facilitate this type of collaborative, interactive, guided inquiry'. The response choices were 'user' (25%), 'modified user' (33%), 'influenced by' (24%), 'considerer' (10%), 'past user' (4%), and 'never heard' (3%). For the purposes of this paper, we consider 'users' to be anyone who responded that they were 'users' as well as people claiming to be 'influenced by', 'using,' or 'considering the use of' the SCALE-UP. The reason for this broad definition of user is that in previous work (Dancy and Henderson 2010), we have found that respondents interpret self-reported user categories in very different ways.

As described above, instructors may only 'use' innovations in a very loose sense. For example, more knowledgeable instructors may deny being a SCALE-UP user if they consciously made a minor modification in their implementation while less knowledgeable instructors who are using only a few ideas from SCALE-UP may claim to be users.

Additionally, since nearly all instructors make modifications, it becomes difficult to define 'use'. As reported later in the analysis, different user categories had very few statistically significant differences in their use of pedagogical and structural aspects of SCALE-UP, thus justifying our decision.

In summary, relying on survey data inevitably adds concerns regarding self-report data. However, since empirical studies on the spread of complex educational innovations, such as SCALE-UP, is limited, these exploratory results lead to interesting and worthwhile hypotheses that we plan to further confirm and refine with interviews and site visits in subsequent phases of our study.

**Results and discussion**

RQ1: to what extent has SCALE-UP spread? Are these rates of spread consistent with Diffusion of Innovations theory?

1a. How many physics departments has it spread to?

Across all disciplines, the survey identified 314 departments at 189 institutions in 21 countries that claim to be influenced by or using some version of SCALE-UP style instruction. Over one third (114 departments) use SCALE-UP in physics (or related fields), making physics the most represented discipline. It is not surprising that SCALE-UP is most widely used in physics since SCALE-UP was originally developed for university physics.

**Table 1 Distribution of departmental affiliation for survey respondents who indicate that their department uses or has been influenced by SCALE-UP**

| Discipline category | Subjects | Percentage of departments |
|---|---|---|
| Physics | Astrophysics, Astronomy, Physics, Physical Science, Physics Education | 37.0% |
| Chemistry | Chemistry, Biochemistry, Chemistry Education | 12.0% |
| Biology and health professions | Biology, Immunology, Microbiology, Health Professions, Pharmacy | 14.6% |
| | Health Professions…………3.4% | |
| Engineering | Engineering | 7.5% |
| Mathematics and statistics | Mathematics, Statistics, Computer Science | 7.1% |
| | Computer Science…………2.6% | |
| Other STEM | Environmental Science, Geosciences, Food Science, Sustainability | 2.6% |
| Non-STEM | Arts, Architecture, Business, Communication, Economics, Education, English, Film Studies, Psychology, Social Studies, etc. | 19.2% |
| | Business…………………………1.6% | |
| | Psychology……………………..1.6% | |
| | Social Studies…………………2.3% | |

1b. How many other disciplines has it spread to?

The other 63% of non-physics departments include over a dozen disciplines, as seen in Table 1. Most SCALE-UP implementations (81%) are in STEM departments. For the rest of the analysis, results presented by discipline will not display the 'other STEM' category because of its small percentage that includes diverse subject areas.

Most implementations are in STEM departments, the majority of which are in institutions that award graduate degrees in their discipline. Thus, as expected, SCALEUP is most widespread in schools and disciplines similar to the development site but, encouragingly, this census shows that education innovations can cross institution types and disciplines. Adopters have a wide range of characteristics, including the fields far from the originating field, such as social sciences and the humanities.

Other notable findings include:

- 16% of the departments using SCALE-UP are outside the United States
- 61% of the departments using SCALE-UP are from
- 4-year colleges/universities with a graduate degree in their discipline
- 23% of the departments using SCALE-UP are from4-year colleges/universities with bachelors degrees in their discipline
- 8% of the departments using SCALE-UP are from 2-year colleges
- 8% of the departments using SCALE-UP are from other higher education institutions (those offering professional degrees, 3 year programs, 4 year programs without a degree in the discipline, etc.).

As discussed earlier, in the remainder of the paper, only results from United States institutions will be reported.

<u>1c. How much does the reform spread within a department?</u>

Even though SCALE-UP has spread widely across departments and institutions, within most departments, this mode of teaching is not the status quo. When compared by discipline, Figure 2 demonstrates that physics has the highest intradepartmental use of SCALE-UP in introductory courses. So even though a growing number of departments use SCALE-UP, across all disciplines, a minority of instructors uses SCALE-UP style instruction in introductory classes. This indicates that this method of teaching is still relatively rare, and thus, the reform is still in the early stages of diffusion within most departments.

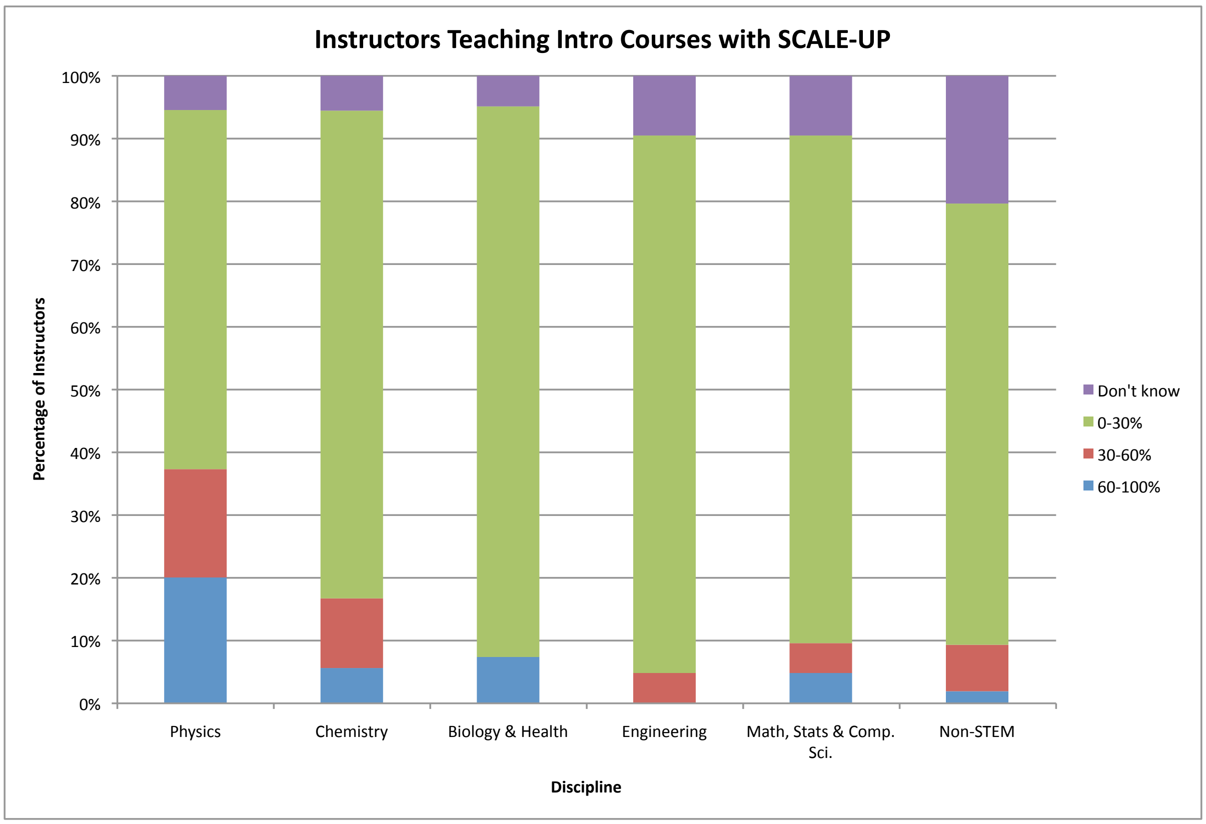


Figure 2: Instructors Teaching Introductory Courses with SCALE-UP

1d. Are these rates of spread consistent with diffusion of innovation (DOI) theory?

According to DOI theory, successful innovations follow an S-shaped adoption curve as shown in Figure 1. To see the spread of SCALE-UP over time, the survey asked respondents how long SCALE-UP style instruction had been used in their department.

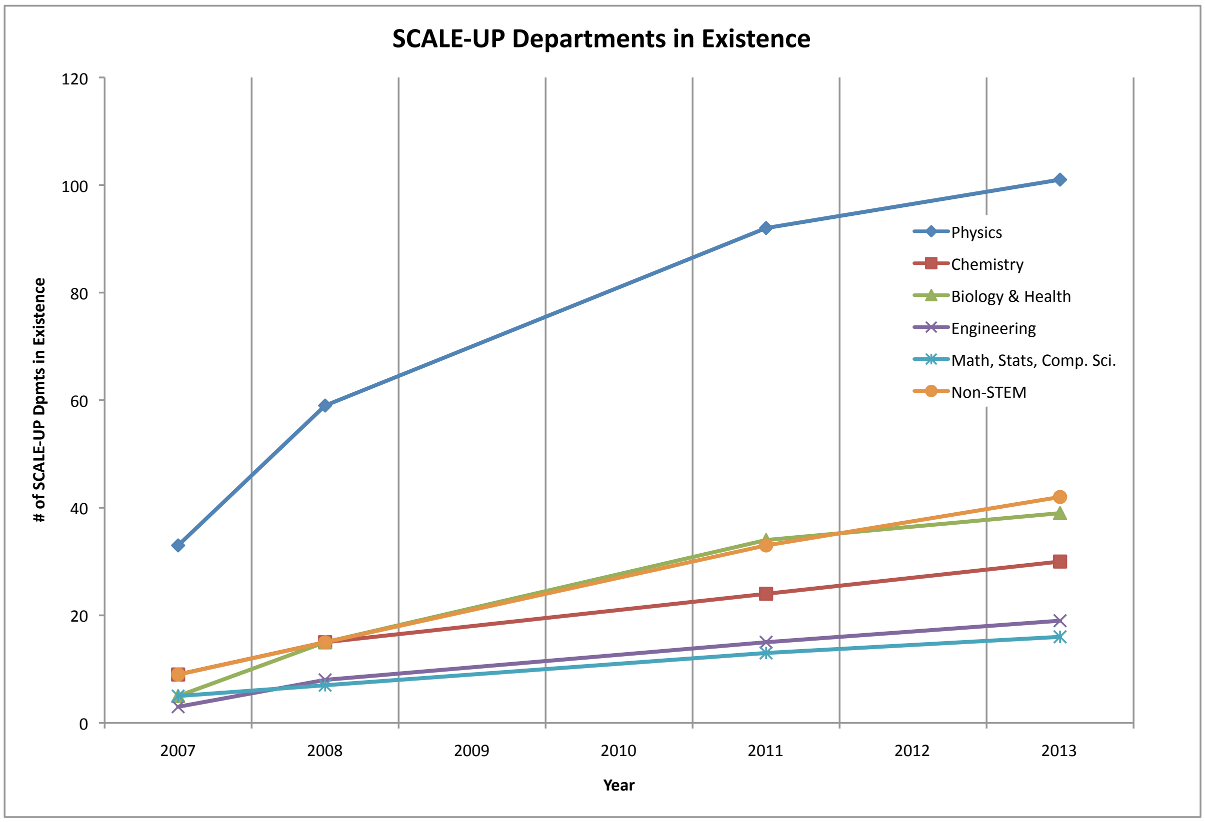


Figure 3: SCALE-UP departments in existence

As seen in Figure 3, physics has been widely using SCALE-UP the longest. The number of biology and non-STEM implementations jumped within the past 4 years. The time scale is not resolved enough to compare this figure to the typical diffusion S-curve (Figure 1) but the general pattern of the beginning stages of spread is similar. Locating SCALE-UP's position on this curve will allow change agents to orient themselves according to the users they may be reaching and may need to reach out to, to ensure the reform's continued spread along the curve. Unsurprisingly, the originating discipline of physics has the largest number of implementations using SCALE-UP the longest. The number of non-physics departments using this reform is increasing. As mentioned in the literature review, DOI theory suggests that early adopters are different from later adopters. Thus, it is important for change agents to locate where their innovation is in the adoption curve. To identify where the use of SCALE-UP by US physics departments is on the adoption curve, we compare the 94 US SCALE-UP departments that offer physics degrees to the 751 undergraduate physics degree departments in the US (Nicholson and Mulvey 2012). This suggests that SCALE-UP is currently (2013) used in about 12% of US physics departments that offer a physics degree. This percentage is approaching the 16% threshold that represents the shift between the early adopter and early majority stages predicted by DOI theory.

While reviewing the names of survey respondents using SCALE-UP in physics departments, we noticed that many actively participate in the physics education research community, a finding again consistent with DOI, which claims that early users are well-educated and innovative in their fields. To continue the diffusion of SCALE-UP among the next group of ‘early majority adopters’, which Rogers (2003) characterizes as deliberate followers who seldom lead, SCALE-UP may need to change its message to appeal to a more mainstream faculty population. SCALE-UP spread appears to be in the early stages for other disciplines, so there is less urgent need to change dissemination strategies in subject areas where adventurous early users continue to adopt since developers can continue to appeal to their desire to be on the leading edge.

RQ2: Through what communication channels does knowledge about SCALE-UP spread? 2a. How do adopters learn about SCALE-UP?

The survey asked respondents how they first learned about and how they learned the most about SCALE-UP. Responses to these two questions are combined in Figure 4. The most common way people learned about SCALE-UP was through in-person interactions (talks/workshops and colleague) rather than through the web or literature. As shown, respondents most frequently report discussions with colleagues as their source of information about SCALE-UP.

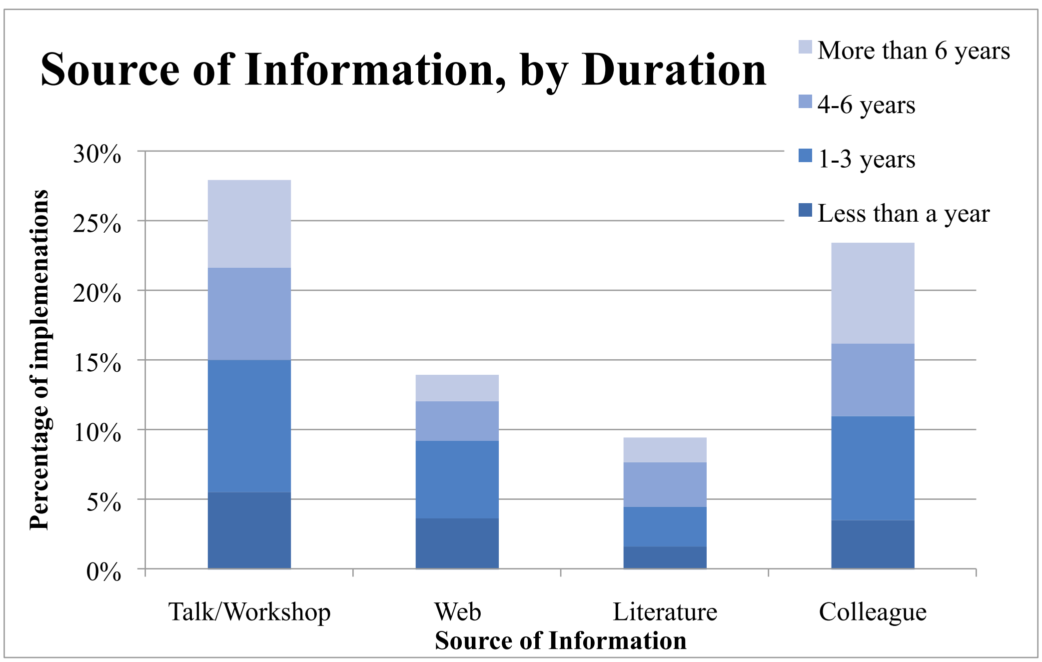


Figure 4: Source of information, by duration of use

This finding is consistent with other studies (Dancy and Henderson 2010; Borrego et al. 2010; Rogers 2003)  that social interactions are a critical to dissemination. It is also a very importants, as the development and dissemination model, does not significantly leverage interpersonal networks, which points to a flaw in that approach.

Communication helps adopters spread awareness about SCALE-UP and share information about implementation.  Many adopters learn about SCALE-UP through 'mass market' channels like talks and workshops (28%), the Internet (14%), and literature (9%). With regard to education reform, mass-market channels like these can reach larger audiences, create knowledge, and may result in change, if people were almost ready. Audiences at talks and workshops already contain many of the characteristics of innovators and early adopters, who tend to adopt a reform first. This audience is probably well educated, social, more up-to-date with current research, and more open to improving their teaching. Mass-market channels often provide an overview of basic information about an innovation: 1) awareness that an innovation exists, 2) how-to knowledge about using an innovation properly, and 3) principles - knowledge about underlying functioning principles. However, information sources tailored to larger audiences do not provide a good platform to exchange personalized how-to knowledge with faculty who want to use the SCALE-UP approach in their unique settings.

Interpersonal exchanges are also significant mechanisms for communication and 11% of respondents claimed to learn about SCALE-UP from a departmental colleague, 11% from an institutional colleague outside the department, and 6% from a disciplinary colleague outside the institution.

Interpersonal exchanges better allow individuals to clarify information, overcome some of the barriers associated with selective exposure, and tend to change strongly held beliefs more effectively (Rogers 2003). The exchange of information between colleagues at an institution, but in different departments, may have facilitated the 'natural' spread of SCALE-UP into other subjects.

2b. How does the communication channel affect the way adopters use the reform.

To examine how the source of information about SCALE-UP might affect implementation, we created two indices from survey responses, 'active indicator' and 'studio match', to gauge the fidelity of the pedagogical and structural use of SCALE-UP, respectively. Since we wanted to see how the instructional practices and classrooms of secondary sites related to the original SCALE-UP model, we created these indices to very roughly compare different implementations on a spectrum of fidelity to the original model. These two indices summarize core features of SCALE-UP in a course, but meaningful way and allow us to compare categories of secondary sites in order to see trends in how they use the reform.

Active indicator: SCALE-UP seeks to minimize lecture in favor of problem solving and student presentations in a redesigned classroom that facilitates interaction. In the survey, respondents selected how frequently they typically lecture, have students solving problems, and have students present to the class (never, very rarely, rarely, often, very often). These qualitative responses were converted into nominal categories ranging from 0 to 4. The active indicator index was then calculated (problem solving + student presentations)/(problem solving + student presentations + lecture). So, an extensively interactive class with no lecturing would have an active indicator of 1 and a completely lecture-based class would have an active indicator of 0.

To put these numbers in perspective, we calculated a hypothetical active indicator for Peer Instruction (Crouch and Mazur 2001), a popular physics reform. In Peer Instruction, ConcepTest clicker questions are interspersed throughout a lecture to expose common misconceptions associated with the material. Students are given a couple of minutes to formulate their response followed by a few minutes to reach consensus in small groups before re-voting.

We estimate that this method would involve faculty lecturing often, students solving problems often, and presenting their solutions very rarely. This would correspond to an active indicator of approximately 0.6. For an ideal SCALE-UP implementation, students would be solving problems very often, present to the class very often, and the instructor would lecture very rarely, which would correspond to an active indicator of 0.9.

Studio match: The 'studio match' criteria uses the presence of tables designed to facilitate group work as a proxy for the presence of a studio classroom, a key feature of the SCALE-UP reform. Our survey asked respondents whether they had a specialized classroom for SCALE-UP and whether they had specific classroom features. We found that people's definitions of 'specialized classroom' vary and may include a renovated lab for some but not others. Furthermore, traditional classrooms can have classroom response systems, whiteboards on the wall, and/or projection capabilities. But the main purpose of the SCALE-UP room is to facilitate interaction. Of all the classroom features, round or special tables seemed to be a key to facilitating group work. We found that this captured 97% of the people who claimed to have a specialized classroom so the table criterion appears to be a good proxy for the presence of an interactive classroom consistent with SCALE-UP. So, the studio match can take on binary values of 1 (special or round tables exist) or 0 (special or round tables do not exist).

Most people learned about SCALE-UP through multiple sources (61%). Of the respondents, 10% learned about it exclusively by reading the literature or researching it on the Internet, 16% learned about it exclusively by talking to colleagues, and 14% have another/unknown source of information. Of the respondents, 53% learned about SCALE-UP from a talk or workshop but all of these people supplemented this with a second source of information.

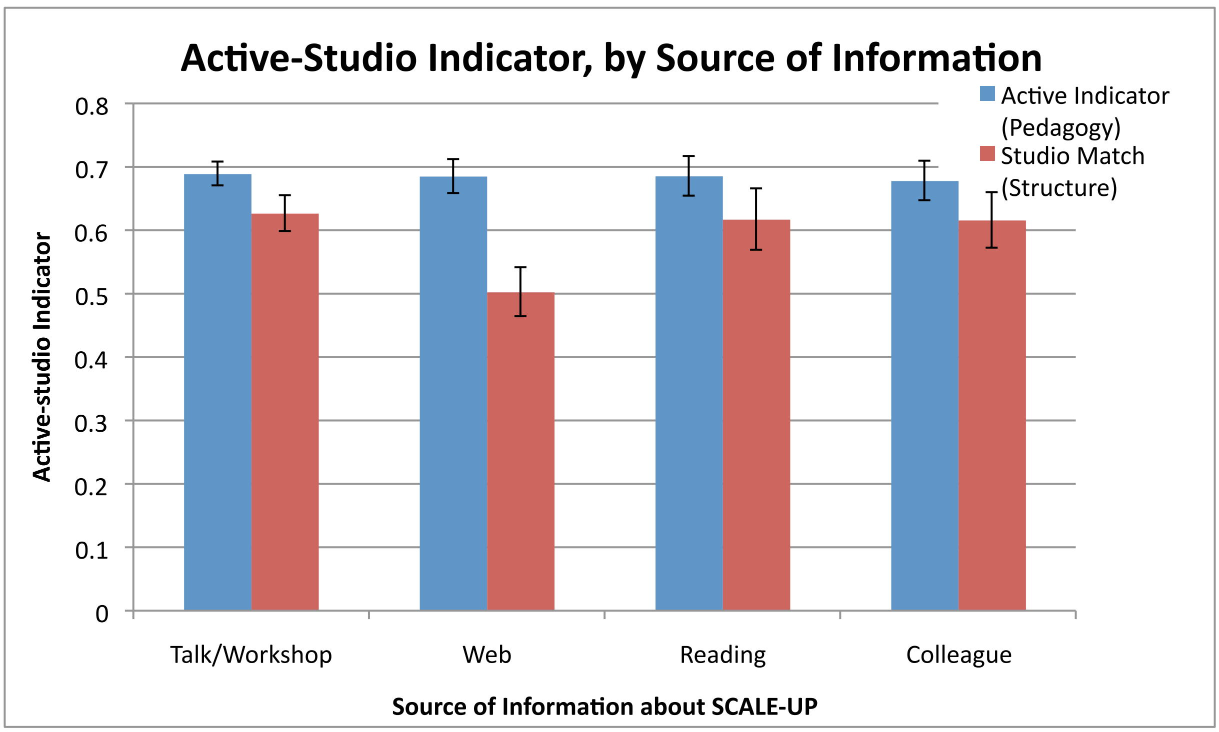


Figure 5: Active-studio indicator, by source of information

As seen in Figure 5, the implementation of SCALE-UP does not seem to depend on information source. The one exception is that SCALE-UP implementers who learned via completely passive modes (the literature/web) are less likely to have a studio classroom.

RQ3: how do secondary sites adapt the pedagogy and structure of SCALE-UP? How does this impact the success of the implementation?

3a. How do pedagogical and structural adaptations of enacted implementations vary by user status? Discipline?

The survey asked the respondents whether they considered themselves 'users', 'modified user', 'influenced by', 'considering', or a 'past user' of SCALE-UP-like instruction.

Only 22 respondents characterized themselves as past users and a follow-up question revealed that only 2 of these were true abandoners (0.3% of total respondents), who did not want to teach using SCALE-UP again. The other past users were not currently teaching with SCALE-UP because of changes in scheduling or teaching assignments but hoped to return to SCALE-UP style instruction in the future. This provides additional justification why it would be inaccurate to use individuals as the grain size to check the pervasiveness of SCALE-UP against the DOI curve. In most departments, not all faculty members are needed to teach using SCALE-UP-style instruction at any given time. Using the department as the grain size helps to account for this.

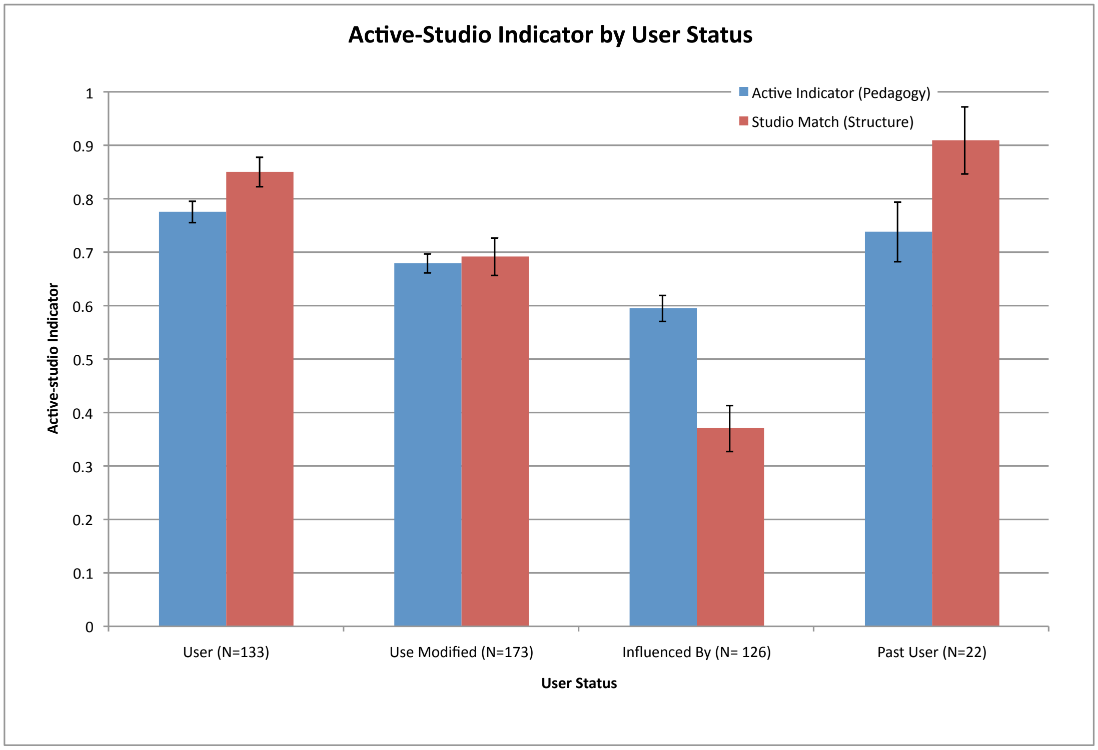


Figure 6: Active-Studio Indicator by User Status

To see how respondents' self-categorization compared to researcher definitions, Figure 6 compares active studio indicators by user status. Not surprisingly, self-described 'users' have higher indicators, both pedagogically and structurally compared to people who claim to 'use modified' and be 'influenced by' the reform. The results of a one-way ANOVA suggests that the differences between the four user groups is statistically significant for studio match ($F(3, 473) = 36.58$, $p = .0000$) and active indicator ($F(3, 426) = 23.32$, $p < .0001$). A Tukey post hoc test revealed that the studio match indicators of users (.88 ± .32) were statistically significantly higher than for modified users (.69 ± .46) and influenced users (.37 ± .48). Similarly, Tukey post hoc test revealed that the active studio indicators of users (.77 ±

.12) were statistically significantly higher than for modified users (.67 ± .15) and influenced users (.59 ± .17). For both indices, there were no statistically significant differences between users and past users ($p = .993$, .969 for studio match and active indicator, respectively). This makes sense because, as discussed above, in this study, ‘past users’ are not true abandoners.

Since SCALE-UP ‘modified users’ and ‘influenced by’ do not have significantly differences in their use of interactive pedagogies and past users are not true abandoners, thus justifying the decision to include all three in our analysis.

Users have the highest structural and pedagogical scores. ‘Modified users’ and ‘influenced by’ have similar (i.e., not statistically different) active indicators but ‘influenced by’ are less likely to have the structural infrastructure to support their use of interactive pedagogies. Thus, these people try to use SCALE-UP style, interactive pedagogies in a more traditional classroom setting.

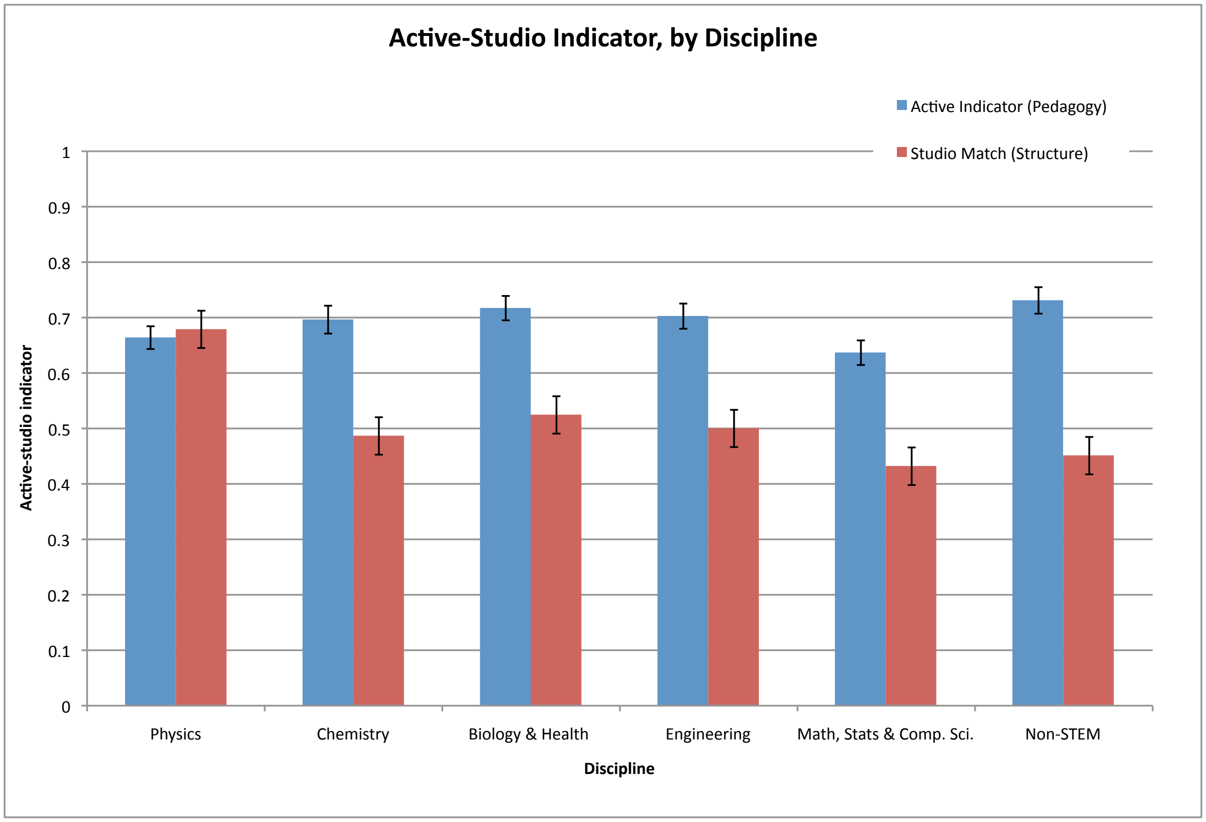


Figure 7: Active-Studio Indicator, By Discipline

As seen in Figure 7, when active studio indicators are calculated by discipline, physics has the highest studio match, demonstrating that structurally, physics has the highest fidelity implementation. Although the results of the one-way ANOVA suggest that differences between active indicators of the six different disciplines were statistically significant ($F(6, 420) = 2.662$ $p = .015$), the Tukey post hoc test did not find any statistically significant differences between any of the pairs of disciplines. Results from the one-way ANOVA with regard to the studio match indicators suggest that the differences between the six disciplines were statistically significant ($F(6, 575) = 4.243$ $p < .0001$). In contrast to the

Tukey post hoc results for the active indicator, respondents in physics have statistically significantly higher studio match ratings than all other disciplines.

<u>3b. How does structural variation (classroom type) relate to use of active learning pedagogies?</u>

The survey investigated enacted use of SCALE-UP at the individual and departmental levels. A full SCALE-UP implementation not only requires modification of existing pedagogy but also re-designs the classroom to promote interaction between students and their instructors and students with each other. Usually, classroom facilities were common to instructors within a department.

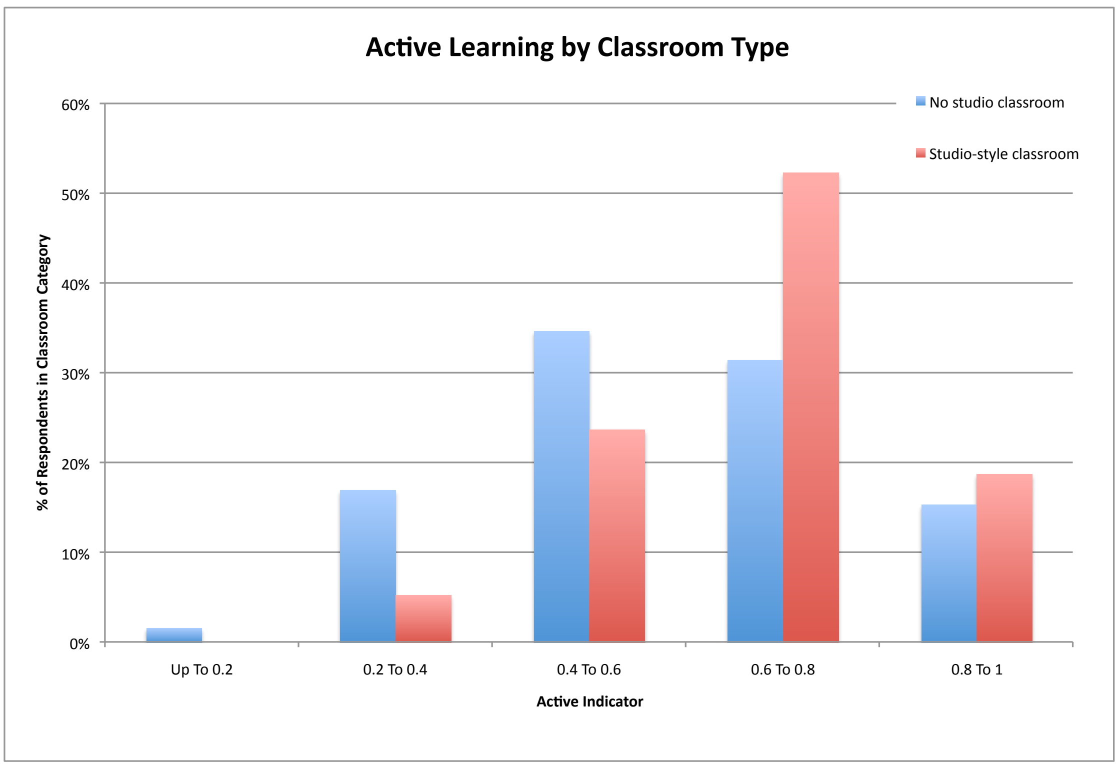


Figure 8: Active Learning by Classroom Type

Of the surveyed departments, 42% have rooms specifically designed to facilitate SCALE-UP style instruction. Figure 8 displays the active indicator ratings for respondents with and without a studio-style classroom.

Respondents without a studio-style classroom spend a higher portion of class time lecturing whereas the majority of respondents with a special classroom spend more time with students involved in activities. This suggests that a redesigned classroom is supportive of pedagogical changes related to SCALE-UP.

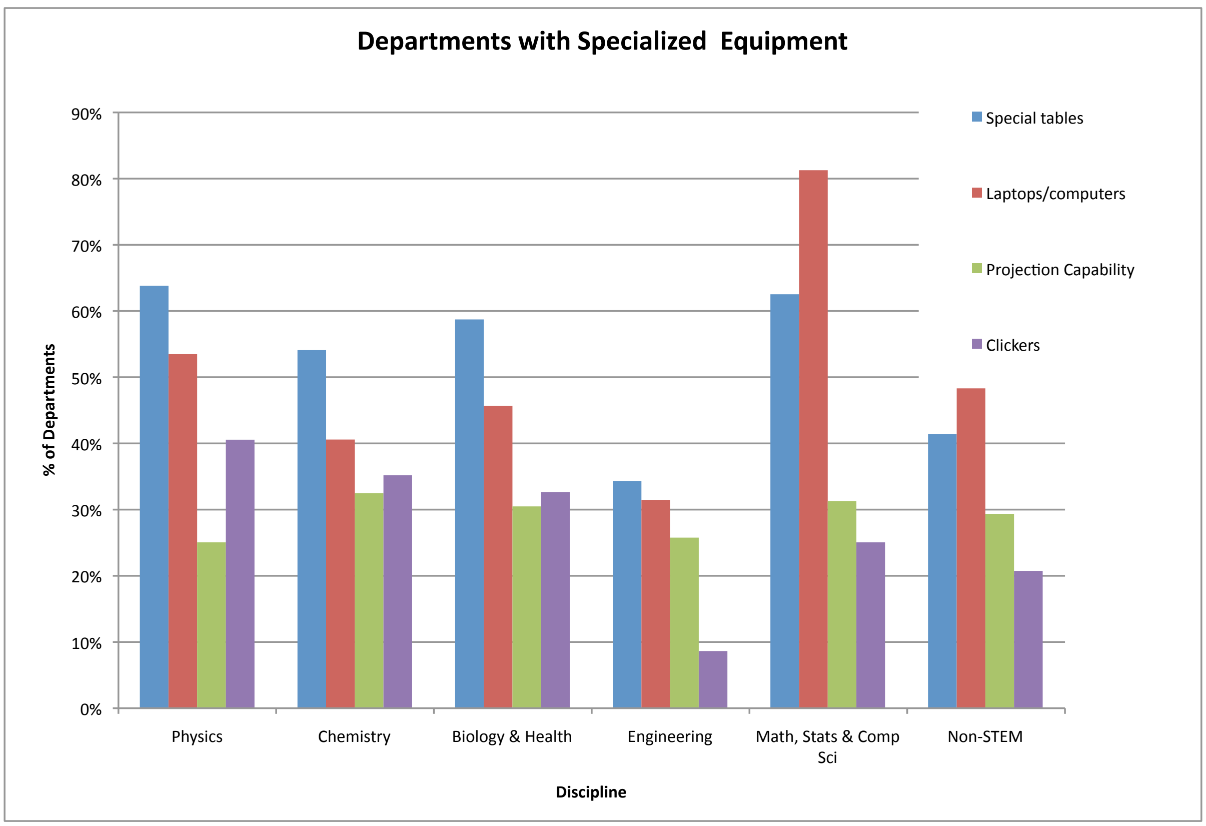


Figure 9: Departments with Specialized Equipment

In the original SCALE-UP model, students sit in three groups of three at round tables, with computers or laptops provided for each individual, handheld whiteboards for each group, whiteboards on the walls as public thinking space, projection capabilities to share student work and a classroom polling system, like clickers (Beichner 2008). Respondents were asked which specialized classroom equipment they had access to. Computers for each individual/group and special tables are the most popular classroom fixtures, found in approximately half of the surveyed departments. However, we felt that these features were not unique to SCALE-UP classrooms so we did not include them in our studio match index. Figure 9 displays the presence of specific specialized classroom equipment by discipline. Not surprisingly, based on the high studio match score, physics has the highest percentage of users with round/special tables, laptops, and clickers, thus following the developer's design. Out of the STEM disciplines, math/statistics have the least amount of specialized room equipment.

Some survey respondents elaborated on unique equipment they use. At some sites, students have access to iPads and scientific calculators and some bring their own technology. For polling, some instructors use smart phone- based polling, a discussion board called Yammer, or old-fashioned voting cards. Some instructors who do not have access to a classroom try to rearrange classroom furniture to sit in groups. Other instructors do the best they can in a typical lecture hall. The variation in special classroom tools demonstrates that structurally, SCALE-UP use varies widely between departments. There is evidence that secondary implementations design their classrooms to promote interaction but not all classrooms look the same.

Several of these departments mention modifying the recommended room equipment to fit their situation, sometimes because of classroom budget/space restrictions or changes in technology (for example, incorporating the use of smart boards and using smart phones for polling).

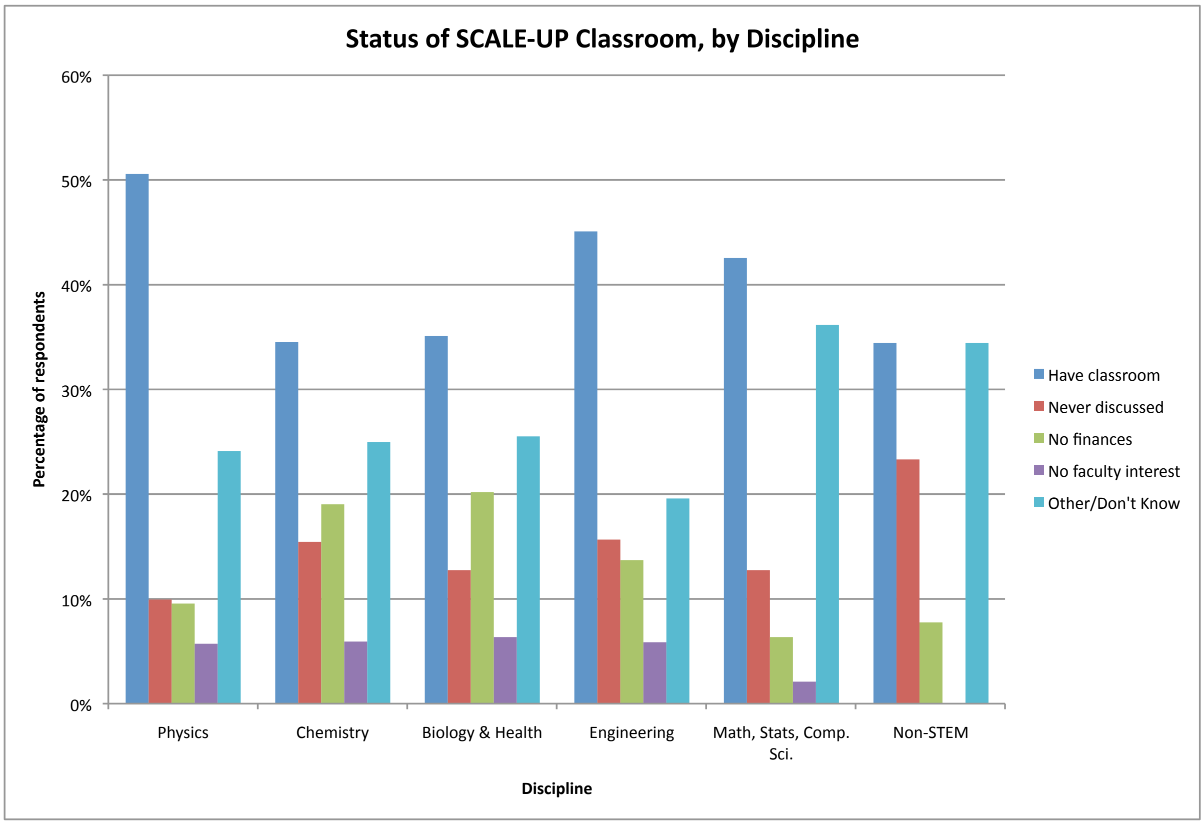


Figure 10: Status of SCALE-UP Classroom by Discipline

To help explain differences in classroom structure, the survey asked the faculty how their department felt about building a specialized SCALE-UP classroom. As seen in Figure 10, approximately, a third of the instructors responded that they have access to a specialized classroom. Other options for responses included: faculty never discussed building a classroom, we had a classroom in the past but not anymore, no finances to build a classroom, or other. In the 'other category', over a third of these respondents explained that their classroom was currently in construction while others indicated that they use a classroom in another department, they are retrofitting a current classroom, or there was no space for this type of classroom.

The lack of financial resources and the absence of discussion inhibit the building of a classroom across all disciplines.

In addition to affecting the status of the classroom, we saw financial limitations impacted how instructors chose to engage their students, for example, using voting cards for polling if a classroom response system was too expensive.

**Conclusions**

The main findings are summarized and discussed below.

<u>Finding one: SCALE-UP has spread widely across disciplines and institutions</u>

SCALE-UP-style instruction has influenced teaching practice in a minimum of 314 departments at 189 higher institutions in 21 countries. Furthermore, in the US, 63% of reported departments using SCALE-UP are outside the originating discipline of physics, and 20% are outside of STEM.

<u>Implication one: encouragingly, this wide spread indicates that SCALE-UP is making a higher than average impact on teaching in higher education</u>

It is beyond the scope of this paper to fully answer what makes the dissemination of SCALE-UP different from similar, but less successful, reform efforts. However, we can point to several attributes of this reform that may contribute to its success.

- SCALE-UP is not discipline specific. As a flexible reform without an accompanying curriculum, SCALE-UP appeals to a broad audience. Having SCALE-UP in multiple disciplines at a given institution promotes cross-disciplinary pedagogical discussions and community building.
- SCALE-UP supports instructor autonomy. Faculty members want ideas that they can adapt to their unique learning environment and personal preferences. They do not what to be told what to do (Cohen and Ball 1990). SCALE-UP provides this guidance and supports a grassroots community via a website (http://scaleup.ncsu.edu/) to share ideas and curriculum.
- SCALE-UP requires structural changes and, thus, has high observability. Renovating the classroom and investing in special equipment can be an initial barrier, but, once crossed, it may also support permanent change and increased dissemination within a department. Deciding to make these radical changes encourages department-wide discussions and buy-in and makes abandoning use less likely. Since structure impacts practice (Henderson and Dancy 2007), it may encourage broader adoption of reformed techniques.
- The developer has extensively leveraged interpersonal methods to disseminate the reform and has not relied exclusively on at-a-distance mechanisms, such as papers and websites. Beichner has given over 300 SCALE-UP talks, workshops, and departmental visits around the world. Each of these potential key attributes will be further investigated in the interview-based, second phase of this study.

Finding two: the dissemination of SCALE-UP in physics may be at the tipping point between adventurous early users and the mainstream majority

The spread of SCALE-UP appears to fit diffusion of innovation theory in terms of the characteristics of early adopters and an accelerating rate of spread. For uptake in physics to continue to increase and follow the S-curve of a successful reform, the marketing message may need to change to appeal to more hesitant potential adopters.

Implication two: diffusion of innovation theory suggests the dissemination strategy of SCALE-UP should change

A rough estimate reveals that physics may be near a tipping point. To maintain S-shaped growth, it needs to cross the chasm from appealing to innovative early adopters to reaching the more practical, hesitant general population.

Moore (2002) states that early adopters are more likely to embrace a radical discontinuity from traditional teaching, to champion the cause against local resistance, and to persevere through inevitable glitches. As many early users in this study were connected with the physics education research community, they are probably more educated about innovative pedagogies and willing to experiment with radical reforms in hopes of drastically improving learning gains. In contrast, the early majority wants to improve existing operations while minimizing disruption to their old ways. They tend to rely more on social networks to learn about and support their adoption, often demand evidence of effectiveness before deciding to adopt and are less tolerant of implementation difficulties (Moore 2002).

To appeal to more hesitant faculty members, the dissemination of SCALE-UP may need to involve more change agents and opinion leaders to cross the chasm to the more hesitant majority. Specifically, implementers may need more guidance from near-peers and opinion leaders to reduce implementation challenges. Leveraging social networks could help facilitate a flow of information about SCALE-UP and provide an encouraging and supportive community. Enlisting the aid of change agents that use SCALE-UP in diverse educational settings may demonstrate to hesitant adopters that they can use elements of the radical reform without overthrowing the status quo. However, since much of the success of SCALE-UP comes from the radical nature of the reform, resources should be developed and shared to ensure that instructors can productively adapt SCALE-UP to their local setting.

Finding three: interpersonal interactions promote successful dissemination

While many people learn about SCALE-UP through typical dissemination via mass-market channels (talks/workshops and the Internet), just as many report learning through interpersonal interactions with colleagues. This is consistent with diffusion of innovation theory and the authors' prior research (Dancy and Henderson 2010; Borrego et al. 2010; Rogers 2003).

Implication three: leveraging interpersonal networks can improve dissemination

The common development and dissemination model of reform does not account for how interpersonal interactions share and support reforms, potentially reducing the impact of existing reforms. A better dissemination model should recognize and utilize interactions as a way to encourage change, especially when trying to reach the mainstream adopters who may not seek out information about a reform. However, this alternate model should cautiously avoid an overreliance on informal dissemination.

An overdependence on word-of-mouth may mean less familiarity with the underlying research outlined in primary sources. If potential adapters only see/hear about modified versions of SCALE-UP, the likelihood of (potentially detrimental) modifications will increase.

Strategically, expanding the number of multi-disciplinary change agents familiar with the underlying research and could help control the quality of information spread through interpersonal networks.

Finding four: a studio classroom is an important feature of SCALE-UP

Our analysis indicates that the presence of a studio classroom is associated with higher levels of active learning. We also found sites without a classroom that attribute this to the lack of faculty discussion or financial resources, rarely because instructors were not interested.

Implication four: it is important to better understand the role of a specialized classroom in the spread of SCALE-UP

Our findings related to the studio classroom are associative, not causal. Learning more at the nature of these relationships may provide valuable guidance for those interested in promoting reform. The presence of a studio classroom is not enough to improve learning gains, if the pedagogy does not match the goal of the renovated room design (Lasry et al. 2014). We found that the presence of a studio classroom is associated with a higher level of active pedagogies and plan to investigate this further.

Renovating a classroom typically requires a financial investment and administrative support so usually it gets departments talking about SCALE-UP. Our initial results indicating a low number of true abandoners strongly suggest that investing in a special classroom reduces the tendency to revert back to traditional instruction. As we continue our study with interviews, we plan to further investigate how building a classroom affects the number of adopters within a department. For example, how does the process of building a special classroom impact faculty who are on the fringes of the reform effort? Do research-based reforms that require departmental discussions (for example, to build a specialized classroom) increase uptake?

Our data suggest that building a special space may reduce the chances of reverting back to traditional instruction. Interviews will continue to probe this initial finding, and future studies should investigate how to apply this to spreading other research-based reforms.

Finding five: reforms are modified

The wide variation of use of active learning pedagogy and studio classroom features demonstrates that instructors differ in their implementation of SCALE-UP. This supports previous research that instructors and departments modify SCALE-UP, both pedagogically and structurally (Henderson and Dancy 2008; Penberthy and Millar 2002; Sharp and McLaughlin 1997; Silverthorn et al. 2006; Hutchinson and Huberman 1994). Respondents reported wide variation in their classroom equipment and active learning levels during their SCALE-UP implementation efforts.

Implication five: secondary sites will benefit from having research-based recommendations on how to adapt their implementation successfully.

Faculty rarely implement an innovation 'as is', usually adapting ideas to their unique environment, goals, personality, and more. Developers should acknowledge this and focus on helping faculty to navigate the difference between productive and unproductive changes, by using change agents or coming up with written recommendations.  They should provide advice on how to overcome structural barriers (i.e., budget limitations that prohibit the ideal classroom design) and other challenges, especially with the less independent, more impatient early majority adopters.

**Summary**

The results of this study indicate that the impact of SCALE-UP is growing and provides insights to guide those interested in educational transformation. Currently, we are conducting interviews to develop a more detailed understanding of how instructors and departments learn about, implement, and spread SCALE-UP. Since instructors tend to make modifications, finding out more about this process can help in the development of resources to support instructor adaptation of the reform to their local circumstances in productive and successful ways.

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**PREFACE TO CHAPTER 4**

My final content chapter was designed to test emerging hypotheses and open questions raised by the previous two studies.

First, I wanted a study that examined the adaption stage of implementation in detail. Study 1 revealed that faculty members made dramatic changes to the reform, often in the direction of traditional instruction, but instructors claimed these were necessary to ensure the survival of the reform with their student and faculty culture. The critical question raised by this study is how adopters can balance adaptability without sacrificing the integrity of reform. Since SCALE-UP is not a simple list of lesson plans or textbook, it cannot easily be directly adopted and therefore requires some instructor input. I want to investigate how instructors navigate adaptations successfully.

Study 2 led to two preliminary findings that I sought to refine in this study. First, according to the literature, instructors are more likely to use flexible, adaptable reforms. I wanted to investigate how instructors took advantage of this flexibility and whether the customizable reform attracted their interest in the first place. Interestingly, three of the professors adopted SCALE-UP with the misunderstanding that it was a "ready-to-go" complete package. They seemed to think they wanted resources that could be used "as is", however difficult formatting caused two sites to abandon use of developer resources all together. Thus, developers should think about providing some resources in a simple ready-to-go format but find ways to build understanding of underlying relationships to guide the overarching curriculum development.

In study 2, we also found that a studio classroom was associated with higher levels of active pedagogies. This study confirmed that the restructured classroom caused instructors to dramatically revision their course materials to include activities. These instructors retained very few of prior instructional materials unless it was good clicker questions or in-class problems. This is promising evidence that the reformed classroom promotes radical restructuring of pedagogy to match the reformed classroom.

## CHAPTER 4: Curriculum development in studio-style university physics and implications for dissemination of research-based reforms

### Abstract

Over the past few decades, a growing body of evidence demonstrates that students learn best in engaging, interactive, collaborative and inquiry-based environments. However, most college science classrooms are still taught with traditional methods suggesting the existing selection of research-based instructional materials has not achieved widespread transformation of undergraduate education. SCALE-UP is a renovated pedagogy and classroom environment which prior work indicates has spread throughout the United States and abroad. SCALE-UP is not a simple collection of lesson plans or a textbook that can be easily adopted and in past work, we hypothesized the flexible form of reform may aid its spread. This paper uses case studies of five sites to see how instructors use this flexibility to chose and integrate composite reforms and customize their implementation. Three institutions misleadingly thought SCALE-UP was a "ready-to-go" package and claimed to want to adopt activities directly, but problematic formatting prevented them using resources from the developer. Many people learned about research-based resources that formed the composite of their curricula through interpersonal conversations. Time constraints and misunderstandings between developers and instructors limited which resources were chosen and how they were used. Implications for dissemination include making basic materials available for immediate implementation but developers must find ways to build knowledge of underlying principles. Involved other secondary users in the dissemination process could alleviate expert-novice differences that lead to misunderstandings.

### Introduction and Motivation

Over the past few decades, a growing body of evidence demonstrates that students learn best in engaging, interactive, collaborative and inquiry-based environments[123]. However, this message has only impacted isolated classrooms while the majority of undergraduate science courses continue to be taught using traditional[4] methods[5]. The existence of a strong research base on effective teaching practices[6] suggests the problem lies in either the dissemination or implementation of methods that lead to successful and/or permanent instructional change.

The first models of dissemination[7] involved a unidirectional, one-size-fits-all information transfer from the "laboratory" to the educational "marketplace." This strongly influenced initial reform efforts, even informing the creation of US Department of Education of laboratories and centers[8]. However, researchers quickly found flaws in this model[9] including that it did not take into account the motivations, contexts and realities of intended recipients. Since then, educational reform literature has shifted to a constructivist perspective[10, 11] where implementers mediate and interpret information in light of their existing knowledge and experiences. Now, much of the dissemination literature acknowledges users are more likely to adopt educational innovations that they can adjust and adapt to their local circumstances[5,8,12]. Fullan and Pompret[13] find users usually modify resources during implementation while simultaneously changing their practice in a process of mutual adaptation within the classroom context.

SCALE-UP[14] (Student Centered Active Learning Environment with Upside-down Pedagogies) exemplifies a reform that has made a larger-than-average impact. A recent census found SCALE-UP inspired reforms are used in at least 314 departments at 189 higher education institutions in over 20 countries worldwide[15]. This reform modifies the pedagogy and classroom environment to minimize lecture, promote interaction between students and instructors and heighten student engagement. Students are seated in groups at special tables, with whiteboards on walls to serve as public thinking spaces, projection capabilities to share student work and no obvious "front" of the classroom to encourage the instructor to serve as a "guide on the side" as opposed to the sole source of information. Instead of the students sitting passively, they work on three categories of activities: "tangibles" (miniature laboratories or other exercises with physical manipulatives), "ponderibles" (intriguing questions that often require estimation or approximation) and "visibles" (computer programming exercises or other ways to visualize abstract phenomena)[14].

Although the studio style environment is important to reform, several studies prove that strictly modifying the classroom does not automatically lead to improved student learning gains. Notably, Cummings et. al.[16] concludes that without activities promoting student interaction and engagement, the "use of the studio format alone does not produce improvement in conceptual learning scores as compared to those measured on average in a traditionally structured course" (p. 44), a finding that was echoed by Ithaca College's initial SCALE-UP implementation[17].

Instead of requiring a specific textbook or curriculum, SCALE-UP uses pedagogy with three main goals: to (1) create a cooperative learning environment that encourages students to collaborate with their peers, questioning and teaching one another, (2) minimize lecture in favor of research-based activities and (3) coach students to help them answer their own questions and let them present their results to the class for review[14]. As more of a philosophy than a strict curriculum, SCALE-UP can, and has been, adapted for use in over a dozen disciplines, a variety of class sizes and institution types. We hypothesize that this customizable format respects and empowers faculty and thus, promotes its spread.

Since the research claims instructors prefers flexible curricula they can modify, examining how secondary sites develop and implement a SCALE-UP curriculum can add practical and theoretical insights for productive ways to disseminate customizable materials that allow professors to participate. Specifically, we can use the process of curriculum development for SCALE-UP as a case study to investigate the following questions: (1) How do secondary learn about research-based resources and decide to use them in a SCALE-UP style curriculum? (2) How do instructors modify resources for use in a SCALE-UP environment? (3) What implications does this have for how developers should package instructional innovations for use outside the development site?

**Literature Review**

In this study, we want to understand how instructors interact with an instructional innovation and its developers during the change process. Models of the change process[18, 19,20] usually involve at least three stages: (1) instructor becomes aware of a problem with current practice (2) instructor collects knowledge about a new practice that can minimize or solve the problem and (3) instructor implements the new practice. Three basic levels of knowledge help facilitate the progression through the second stage[19]: "awareness" knowledge that the instructional strategy exists, "how-to" knowledge about how to use the strategy properly and "principles" knowledge about why the strategy works. Understanding the underlying foundation is essential for solving unexpected problems that arise during use.

How the disseminator frames this information can affect how an instructor receives information and subsequently perceives the reform. This interpretation can be further affected by the instructor's preexisting knowledge, beliefs, experiences and current situation. Researchers and instructors belong to separate discourse communities with different values and ideologies. This complicates this knowledge transfer and can impede utilization[12,21,22].

Agents cannot simply communicate the policy and expect immediate understanding; instructors need time to interpret the reform and figure out implications for behavior. Incomplete comprehension can lead to adopters using the innovation differently than intended. Although adaptation can enhance the utility of a reform and improve the likelihood of sustained use, it can also mutate the form so significantly that it loses the shape and/or the outcomes that originally attracted the user[23,24]. A fragmented understanding about the reform can also lead to what Fullan[19] describes as "false clarity" when teachers describe their behavior as consistent with reform when outside observers disagree with their characterization. For example, teachers may claim to use Peer Instruction or another reform in their classroom but may not be implementing the complete procedures as originally designed[25].

For example, instructors may interpret a reform as prescribing certain activities without a coherent idea of the underlying idea. This may especially affect radical reform efforts like science-by-inquiry, student-centered classroom and SCALE-UP, which intend to revise not only classroom activities but also the cognitive practices of scientific reasoning and the social interactions of learners and their instructors[26,27].

> "Such reform cannot be accomplished by having teachers learn only the surface form of reform practices. It requires grappling with the underlying ideas and may require deep conceptual change, in which teachers rethink an entire system of interacting

attitudes, beliefs, and practices"[21] (p. 417).

Instructors are not blank slates: they need to integrate the new idea with their existing cognitive structures (including knowledge, beliefs and attitudes), their situation and the policy signals.

**Sense-making Framework**

Since these elements may influence how implementers understand SCALE-UP and proceed to form a curriculum, we want an interpretative framework that accounts for this. Spillane et al.[21] propose a sense-making framework grounded in individual and situated cognition, drawing on work concerning implementing agents' prior knowledge[28] and the analogies that they draw between new ideas and their existing understandings[29]. This framework also discusses how aspects of the social situation influence implementing agents' sense making, such as organizational and community history[30,31], organizational segmentation[32], and social interaction in formal and informal networks[33].

The first element of the framework applies to how individuals comprehend and make sense of innovation. In a traditional "one-size-fits all" dissemination model, implementer's deviations from policy can be condemned as purposeful efforts to damage implementation. Yet, in many cases, agents faithfully attempt to replicate reforms but fail. Inevitably, teachers' prior beliefs and practices influence how the new message is interpreted and can interfere with their ability to implement the reform as designed. As Cohen and Weiss[28] wrote, "when research is used in policy making, it is mediated through users' earlier knowledge, with the policy message 'supplementing' rather than 'supplanting' teachers' earlier practice" (p. 227). What is understood from a new message depends critically on the knowledge base that one already has; their views of the discipline, views of students, and ideas about what it means to teach science. Thus, this sense-making framework implies that successfully learning new instructional approaches involves more than adding new facts: in some cases, it may require restructuring a complex of existing theories about what education means.

Complicating this process, people (especially novices) often rely on superficial similarities when accessing remembered information even if deeper principles are more appropriate[34, 35], in a similar manner to students approaching novel physics problems[36, 37]. The difficulty this poses for reform is that agents with less expertise in educational innovation may misleadingly rely on superficial similarity, assuming that two situations are fundamentally similar when only salient features appear alike. For example, teachers may not distinguish between two teaching scenarios that both use concrete manipulations but for fundamentally different purposes: one where the manipulatives promote reformed exploration and discourse and the other where the tools are used in a basic, procedural way[38]. The interference of individual cognition can culminate in people forming different interpretations of the same message, people understanding new ideas as familiar (thus eliminating the perceived need for change) or missing deeper relationships because of superficial aspects of reform[21].

Implementation practice is not simply a function of an individual agent's ability, skill and cognition since the surrounding situation and social interactions often affect the execution of particular tasks[39]. Individuals do not make sense of their world in a vacuum but instead "thought communities"[40,41] (such as professions, nations, political parties, religions, and organizations) situate their sense-making. In the second component of our framework, we consider how organizational and historical context, formal and informal communities and communal values and emotions affect sense making. Knowledge is distributed and emergent from the interactions of the participants in a given setting as individuals learn from one another and uncover insights and perspectives that otherwise might not be obvious to the group[42,43]. Thus, the context and social interactions surrounding reform can affect how implementers understand the reform.

A third and final component of this framework is how developers present the policy. Policymakers need to represent ideas about instruction in ways that enable sense making, incorporating both concrete examples and underlying theory. The literature contains some recommendations on how to frame policy to facilitate this process. In order for implementers to perceive a need for change, policy makers must create a sense of dissonance in which agents see problems with current instruction to an extent that they are willing to supplant, or fundamentally change, practice. Once agents recognize problems with the existing model then they can restructure existing beliefs and knowledge to make sense of the new idea. For reasons stated above, this process is not trivial and policy makers must structure dissemination accordingly. Cohen & Hill[44] find policy is more likely to influence teaching when teachers' opportunities to learn are extended over time, grounded in the curriculum that students study, and are connected to several dimensions of teaching.

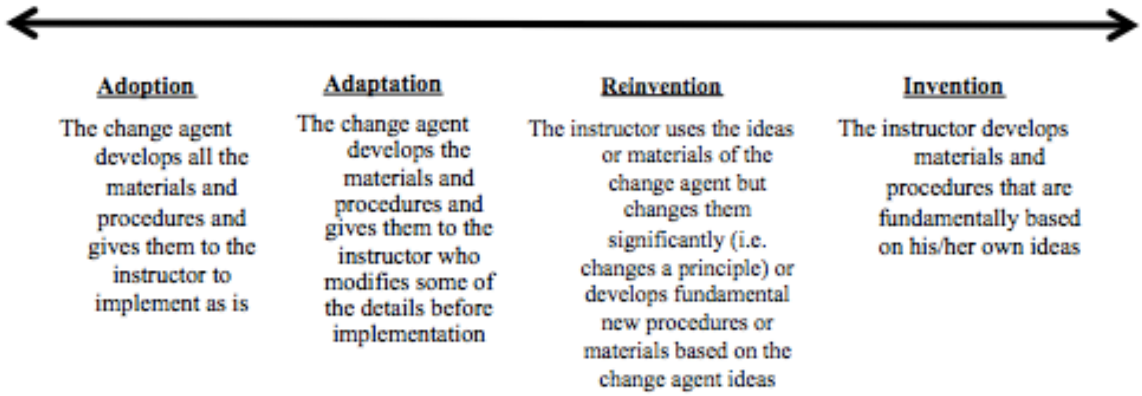


Figure 1: Adoption-Invention Continuum (Ref. 12)

**Adoption-Innovation Continuum**

Although the sense-making framework is important for understanding how people conceptualize the SCALE-UP reform, ultimately we want to identify how extensive are modifications made to research-based materials when used in a studio-style environment. We want to account for change processes that vary according to the involvement of the external change agent and the instructor. Henderson and Dancy[12] provide such a tool: a continuum that spans four categories, from an adoption pole to a reinvention pole (Fig. 1). At the left-hand extreme, the change agent develops all the materials and procedures for "as is" adoption by the instructor. At the opposite extreme, the instructor views educational research as irrelevant and develops everything with minimal external influence. In between, for adaption and reinvention, an idea that comes from an external source inspires the instructor but they develop important aspects of the strategy independently, usually without the assistance of the developer. The resulting instructor-developed strategies may or may not be in line with research-based practices from the literature[45,46,47,48,49,50].

This continuum will help identify how research-based materials are adapted and contribute some insight to why. In some cases, the implemented form might depend on the innovation itself. For example, some tools were designed for immediate classroom use and are unlikely to be modified like assessment instruments such as the FCI[51]. For other materials and reforms (including SCALE-UP), pure adoption is not possible. For example, the developers of Physlets made a flexible technological resource for classroom demonstrations for use according to the instructor's preferred pedagogy[52]. SCALE-UP also falls under this category— it outlines main pedagogical goals but leaves the choice of content and structuring of activities up to the instructors. While the nature of the innovation can influence whether a reform can be strictly adopted, the instructor's background, perceptions about the situation and instructional goals can introduce further modifications.

**Research Questions**

1) Why did the implementer seek reform? How did they decide to adopt SCALE-UP?

- What was the problem with prior instruction? What are goals for implementing the reform?
- What social interactions surround reform initiation? Where do they get knowledge about the reform? What experiences do they bring?

2) How did the reformer's perceived needs and knowledge about research-based materials influence their choice of curricular materials for SCALE-UP?

- How did the reformer's understanding of SCALE-UP contribute to their choice of curricular materials?

- What reforms did they choose to incorporate and why?

3) When forming a SCALE-UP curriculum, how do implementers implement research-based materials? What changes are made and why?
   - Where do implemented materials fall on the adoption-reinvention spectrum?
   - Why do instructors adopt some materials as is and change others?
   - What resources do they feel they need to "invent" themselves and why?

## Methods

### Data Collection

Since we want to understand how people navigate the curriculum development process successfully, we examined "successful" secondary sites with a direct link to the SCALE-UP developer and development site (Robert Beichner at North Carolina State University). We defined "successful" as have achieving sustained use of the reform and 100% usage in introductory physics courses. The course under consideration is calculus-based introductory physics because this course has been the focus for many reform efforts in PER and can be compared across institutions. All of these institutions have dedicated Studio spaces, with 7' round tables (seating nine students per table for a total of 45-117 students), whiteboards on walls, projection capabilities and student access to computers. Although some institutions use different acronyms, for this study, all reform efforts will be referred to as "SCALE-UP" to preserve anonymity.

These institutions were also selected because since they span the adoption-invention continuum, with two institutions attempting to replicate the reform as closely as they could and others purposefully adding and modifying significant elements. Instructors in three of these efforts had no formal background in PER (Physics Education Research) when they initiated the change. Thus, faculty involved in this study represent likely adopters of reform: both people who are actively involved in the PER community as well as "typical" university professors who have an interest in improving instruction but no formal background in physics education research.

| | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **Basic** | 4-year private, more selective, majority undergrad. | 4-year public, medium, selective, high undergrad. | 4-year private, more selective, very high undergrad. | 4-year private, more selective, majority graduate | 4-year public, more selective, majority undergrad. |
| **Approx. Student Pop.** | 25,000 | 24,000 | 7,000 | 10,000 | 29,000 |
| **Research Institute ?** | RU (very high research) | RU (high research) | MC (larger programs) | RU (very high research) | RU (very high research) |
| **SU year?** | 2008 | 2009 | 2006 | 2004 | 2010 |
| **PER faculty?** | No | No | Yes | No | Yes |

**Figure 2: Institutional profiles based on Carnegie Classification, all institutions are full-time, RU= Research University, MC= Master's College**

Since this study primarily concerns the process of curriculum *development*, we focus on the initial implementation of the reform. We focus on understanding the process for the first key implementers at the institution, who lead efforts to develop a curricular package to pass down to future instructors. We spoke to at least two people at each institution, and interviewed the key implementer at least twice. The open-ended interviews lasted at least one hour and the first session gathered information about the general initiation story (For example, where did you hear about SCALE-UP? Why did you decide to try SCALE-UP? How familiar are you with physics education research? What did your instruction look like before and after reform?). The second interview was conducted after class observations and course materials were reviewed. Questions focused more specifically on the details of curriculum development and to explain observations from the other data sources (For example, what resources did you consult? How did you choose a textbook? Did you consult PER resources? Which ones? Why or why not?).

In addition to interviews, site visits were conducted and I observed between two and six classes at each institution. Initial efforts involved videotaping the class but there was too much activity in the large classroom to create an accurate, comprehensive record on videotape. Instead, the observer took detailed, minute-by-minute notes on class activities, instructor and student engagement.

We collected materials from the key initiator's curricula that tended to get passed along to other instructors, including syllabi, daily Power Points screens and lesson plans, laboratory guidelines, quizzes and exams. Usually, each current introductory physics instructor uses a slightly (or substantially) different set of materials. Although a variety of classes were observed (since the initial developers were not always teaching the semester of observations), there was no attempt to understand the curriculum development process for each individual. For this reason, the class observations and curricula alone were not used as a data source on their own, but instead formed a basis for discussion during interviews. These data sources were also triangulated to verify interview data.

Finally, any related research literature, final reports to funding agencies and information on the web about the implementation effort were also reviewed.

To further verify and validate results, summary reports regarding the implementation effort at each institution were sent to the interviewees for further verification of accuracy and completeness. Additionally, each interviewee was sent a draft of this manuscript for approval.

**Analysis**

All data from an institution was combined to create a coherent representation of the reform effort at an institution and a time-line of the initiation story for each institution was constructed. We also created an accompanying list of composite curricular influences based on course materials, publications and interviews. These were then classified on the adoption-innovation spectrum based on interview's responses to clarifying questions and verified by class observations and course documents.

In addition, the qualitative information from interviews was used to create an exploratory model to describe the process of curriculum development. The model aims to describe a hidden mechanism that explains an observed pattern, which adds explanatory power and leads to growth of theory. To achieve this aim, Clement's levels of knowledge[53] informed the analysis. Level 1, at the base of the hierarchy, is primary-level data in the form of individual statements made by the instructors during an interview. Level 2 is observed patterns and empirical laws, for this study, in the form of similar ideas expressed in the statements made by different instructors. For example, instructors often wanted to use preexisting activities but quickly abandoned this idea if they could not use materials immediately. Level 3 contains researchers' explanatory models. In our study, we notice misconceptions about the nature of the reform can constrain curricular decision-making. Finally, Level 4 is formal principles and theoretical commitments that result from repeated testing and refinement of explanatory models in a variety of situations. Thus, this initial generative study cannot lead to any Level 4 claims.

**Results**

We will present a summary of the implementation story and approach to curriculum development for each institution then present emergent themes in the conclusion and discussion sections. Table 1 summarizes the composite research-based reforms at each institution and where they lie on the adoption-reinvention spectrum.

**Institution A:**

SCALE-UP was started at institution A, not because there was higher failure or a perceived problem with existing instruction but because faculty member Aa wanted students to be more active in the classroom. He recalls, "Basically, my motivation was that students need to do more and construct their own learning". The faculty member visited NC State and in collaboration with a supportive department head, started SCALE-UP in a renovated 36-person studio classroom (6 six-foot tables of six students) in Spring 2008.

Beichner visited Institution A to give a workshop but instructor Aa, who had no formal PER background, developed curriculum almost single-handedly. Before SCALE-UP, he taught algebra-based physics which involved lecture, clicker questions and solving example problems at the board. When he switched to SCALE-UP, instructor Aa recalls he intended to follow the NCSU model as closely as possible; "My initial goal was to clone what you guys did at NC State. It was kind of tried and true… so I wanted to pick it up and use it here". However, he found the materials provided by the developer were not easy to implement as is, "I found that taking NC State SCALE-UP and plunking it here wasn't that straight-forward because things were in this disarray. So I personally ended up using very little of Beichner's stuff because it was too hard to sift through". Furthermore, the developer dissuaded instructor Aa from making the dramatic switch to the Matter & Interactions[54] curriculum that NC State uses. He chose Knight's textbook[55], because it presented the material well and found its workbook problems could be easily adapted to in-class exercises. When looking at the Knight textbook and workbook[56], Instructor Aa found "things were so compelling, well organized and problems were good" and he found that he could modify questions from the Knight workbook into pre-reading quizzes, clicker questions and homework problems with minimal changes.

To develop curriculum, he had to come up with new slides, modify laboratories and coordinate class activities. Previous semester's slides had too much content to be useful, except for good sample problems or clicker questions. Much of the effort was "ripping out lecture material… and filling it with choreographed series of questions— conceptual, conceptual, maybe a numerical stuck in here— leading to a tangible and interlude to a new topic". The instructor also had to develop new labs, starting with nine the first semester. He elaborates, "I tried to take away the cookbook labs we had and introduce a little bit more of the sort of open-ended labs". He either condensed directions from past laboratories or made new laboratories with a simple one-sentence instruction like "determine the spring constant of the ballistic launcher apparatus, by any means of your choosing". For labs, he followed

Beichner's advice of having some groups engaged in video analysis while others did the experiment, then rotate. During the first semester of SCALE-UP, he tried a VPython[57] activity that the students enjoyed but regrets that he never made time for computational activities again. He felt that his implementation was short on tangibles since he lacked creativity to come up with them.

In general, instructor Aa felt satisfied that he achieved a very active class, using modified Knight materials, and did not search extensively for more resources. "I didn't have the time to go and seek out research-developed resources…. I look at the slides each year but a more external search, like looking through the PER literature for tangibles or class activities, I never did…. not by design, by laziness." Instructor Aa has not taught the course since 2012 but SCALE-UP has been going strong in his department and he passes his notes to new instructors. After the pilot, the classroom was later doubled to fit 54 students (6 seven-foot tables of nine students) to give students more space, especially for experiments. In 2013, all introductory classes switched to a SCALE-UP format, almost naturally, without a major debate.

**Institution B**

At institution B, two interested faculty members (Ba and Bb) became interested in SCALE-UP when they heard Beichner speak, one at an off-campus workshop and the other at an on-campus seminar. They decided to visit NC State to observe SCALE-UP classes and meet with local experts. These faculty members had no official background in PER, apart from reading literature and hearing PER researchers speak on campus (the researchers behind *Peer Instruction*[58], University of Washington *Tutorials*[59] and *Teaching Physics With the*

*Physics Suite*[5]). As a state school, administrations at Institution B are always concerned with decreasing DFW rates but, for these instructors, this was more of a positive by-product than a major motivator. Instead, they wanted to try something new and their department supported innovative teaching. The pilot classroom (four 7-foot tables that sat 36 students) was ready for use starting in Fall 2009.

To begin the effort, they brought one of Beichner's graduate students to campus multiple times to help initiate the reform and train faculty. When choosing a textbook, they considered M&I since NC State was using it but Instructor Ba remembers that they "decided it was a little too radical and it would make it hard to switch back and forth between the two classes, maybe a little too different for us". They considered traditional textbooks too but decided on *Understanding Physics*[60], as "a compromise between the very radical M&I and traditional and it did come out of the PER community so there was a sense that this is written with a PER sense in mind". Later, this book was abandoned since it lacked mathematical rigor and they have tried two (more traditional) textbooks since.

They tried to implement NC State activities but this was quickly abandoned because "the formatting wasn't really right" (Ba). Instead, they created their own curriculum, alternating between one writing the slides and the other editing. They felt they had to "start from scratch" and do a "complete restructuring" when they switched to SCALE-UP in order to come up with ponderables and tangibles and coordinate with the new textbook. They borrowed some materials from Peer Instruction (which they used before) and conceptual questions from *Thinking Physics*[61]. Through informal conversations with research colleagues, they were able to borrow a few activities from other institutions doing SCALE-

UP but in an ad-hoc way. They abandoned two-hour traditional PASCO labs that preceded SCALE-UP and tried to come up with labs that were simpler in terms of procedures and equipment. However, they never developed enough so they eventually removed the integrated lab and are still working on this component.

They claim their SCALE-UP implementation started off "really orthodox, the way things were done at NC State" but over several years, especially when other faculty members started teaching it, "some of that was dispensed with- the groups, the nametags, roles, we at least assigned them and used them to different degree, mostly because of laziness but also because the outcomes didn't seem worth the effort", according to instructor Ba. The pilot seemed to work well with a regular and honors class so they expanded their classroom so it could accommodate 90 students. Now all introductory calculus-based physics classes are taught with SCALE-UP. They discussed the possibility of eventually moving to the Matter and Interactions textbook later on but the instructors do not seem to think that will happen in the near future.

**Institution C**

Instructor Ca had a history with reformed teaching because of involvement with a teacher seminar run by the physics department at Oregon State University for eight years. After starting a new faculty job at Institution C, he attended the National Science Foundation New Faculty workshop in 2003. When Beichner spoke about SCALE-UP, this model resonated with his experiences at this institution, which has historic roots as a music school. He felt it would also improve logistics since because as a primarily undergraduate institution in the traditional model, a faculty member must be present to run the 24-student lab sessions.

Switching to SCALE-UP with an integrated lecture-lab-recitation in a 99-student room made faculty teaching more efficient as well as possibly increase learning gains. Instructor Ca proposed adopting the reform during the college's 5-year planning assessment and found administrators to be enthusiastically receptive. They invited the developer to campus to speak, ran a pilot class in 2005 (where students had access to some data collection equipment and laptops) and began using a full-scale room in 2006.

At Institution C, the majority of students studying physics take the algebra-based version whereas the calculus-version was taught in a smaller lecture hall, typically for two sections of 30-40 students. Instructor Ca had been incorporating Peer Instruction[58], Think-Pair-Share[62] and University of Minnesota *Context-Rich Problems* (CRPs)[63, 64] into the calculus-based course prior to making the switch to SCALE-UP. He used both of these in fairly strict accordance to the literature, including UMN's recommendations for creating groups for Cooperative Group Problem Solving[64]. After about 5 weeks, he found the stock CRPS were "too easy" for his students and he modified them to provide less information (to promote estimation) and contain more distracters (so they would critically evaluate their assumptions). He also developed his own scoring sheet to grade the problems and improve feedback for his students.

Since he had an active class already, he found it easy to move to a room that better facilitated what he was already doing. The scheduling switched from three 50-minute lecture sections and a 75-minute recitation to three 2-hour meetings. To fill the time, he created hands-on activities and expanded the CRP problem solving to fill longer sessions. Calculus-based physics has a separate, formal laboratory course meant to refine experimental skills so these were not formal exercises. He explains that during these activities, "students would explore phenomena before instructor discussion and explanation. An example of these activities is having students use carts and tracks to explore the effects of collisions… followed by Think-Pair-Share questions using clickers". Some of the activities were found on the web and Instructor Ca developed others himself.

Originally, he considered using some resources from NC State but the server of the SCALE-UP database crashed during implementation so this was not an option. He recalls, "We were expecting a guidebook so that Bob could just go, here is SCALE-UP, now go. At the time, and I think still, there's no guidebook". Although he personally knew enough about the reform not to expect a *Workshop Physics*[65] curricula or a specific textbook, he still expected more structure and said it took three years of conversations with the developer before he realized how "loose" the reform is. When he advises other potential SCALE-UP sites, he tells them SCALE-UP does not come with a curriculum, instead it is a mode of Instruction that integrates lecture, lab and recitation. He explains, SCALE-UP "allows you to take advantage of these other approaches… And how do we take advantage of that? We happen to be using more think-pair-share, more tutorials but the core of it is cooperative group problem solving."

After his first time teaching the course in SCALE-UP, he did not make major modifications to the curriculum. The group of instructors for the introductory physics course sequence switched the textbook from Young and Friedman[66] (which he used to continue the tradition of the course predecessors) to Knight[55] to Mazur[67] but after this instructor taught the course. A PER paper[68] convinced him to modify how he administered reading quizzes in

2007 so the students brainstormed questions during reading instead of using clickers to assess understanding. Overall, the instructor found having a history with interactive teaching, developing the course independently and working with smaller class sizes in calculus-based made it a smooth transition to SCALE-UP. Converting the algebra-based physics courses took multiple iterations and more dramatic curricular changes before they could achieve satisfactory learning gains, potentially because of challenges integrating the lab component and dealing with a different student demographic. In this calculus-based course, the gains consistently met the instructor's expectations based on national benchmarks.

**Institution D**

Instructor Da first learned about SCALE-UP when he visited campus because of a research collaboration on another PER-related project. Although this project involved developed 3-D visualizations and applets to aid understanding abstract electromagnetic phenomena, instructor Da openly admits "I am not a PER person" even though he is a senior faculty member with a good reputation in the department. Instructor Da had been teaching the mandatory second semester of the introductory physics sequence and he was frustrated with the high failure rates (~10-15%) and low attendance (~40%). He felt like he "mastered" lecturing but realized that it did not matter how well he presented the material if the students did not show up for class. He felt SCALE-UP looked like a "better" way to teach and thought it could encourage the students to come to class without having to explicitly mandate it. Before SCALE-UP, he used Peer Instruction in lecture hall, potentially because his colleague Db (a permanent lecturer) had been working with Mazur (the developer of *Peer Instruction*) on a textbook project.

Instructor Da secured funding and support from administrator because of the high failure rates. His colleagues supported the idea of the reform since it would reintroduce laboratories that had not been part of the physics sequence since 1971. He renovated a classroom and began preparing to run two trial sections in 2001 and 2002 off-term. Instructor Da and Instructor Db together worked to develop curricula and both instructors taught a section in the early prototype courses. Instructor Db had a history working with an experimental, activity-based elective physics course on campus.

The first year, the instructors had to develop content: they wrote a book (so students could access a free textbook online), instructor Da worked on integrating his visualizations and they wrote 19 experiments. Some of these experiments were standard, from the manuals accompanying lab equipment and some were adapted from the experimental course. The students in the experimental group typically built the apparatus themselves but this step was eliminated because of time constraints and the large class size in SCALE-UP. Although they admit NC State strongly influenced the classroom design, they felt like they were better off making their own content "that made 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" (Instructor Db) in anticipation of student and faculty pushback. Originally the reform started with lecture and clicker questions, which were developed in-house but inspired by Mazur's ConcepTests[58].

The SCALE-UP pilot sections were met with success so they converted the on-term sequence in 2003 to this format, which was met with significant resistance from students. Instructor Da fought most of the political battles and Instructor Dc (a new tenure-track faculty member) took over managing the course. Instructor Dc introduced board problems and initially groups tried to solve them as a table of 9, which meant some people stood around with nothing to do. He realized that he could raise projection screens to create more board space and students could work in groups of three.

In contrast to other institutions, Institution D continued to make modifications every year to increase interactivity. Instructor Db began enlisting undergraduates to work as Teaching Assistants (TAs). He assigned each TA to focus on helping few tables so they could build familiarity and identify potential problem situations with students and serve as role models (especially to underrepresented students). This helped mitigate student resistance. They also realized 19 laboratories were too many and cut down the number of experiments and chose activities that were "not so much about data-taking but about learning the concepts behind whatever the phenomena was" (Instructor Db). In 2014, they integrated resources from edX Massive Online Open Courseware version of the course into their in-person class to improve reading quizzes and provide additional reference materials.

**Institution E**

Two lecturers (Ea, Eb) with PER PhDs at Institution E had previous experience with studio instruction during graduate school. Instructor Ea went to graduate school at North Carolina State University and helped teach SCALE-UP during its development phases. Instructor Eb studied at Kansas State and wrote a dissertation on perceptions of studio instruction. Although Ea had shown an interest in starting SCALE-UP from the beginning, he knew he could not do it alone. The department head (Ec) became interested in PER and her sabbatical spent reading the research literature was the turning point to make SCALE-UP a reality.

Before SCALE-UP, Ec describes, physics “lectures were all running on an independent track each taught by a different person who was doing their own thing, recitations where TA's are droning at the blackboard, lecture, traditional labs”. Although dropout rates were not a major concern, there was a general sense of discontentment about the state of the courses: students were frustrated about having to complete “cookbook labs” and conceptual gains were not as high as they could be. To start the reform, the department head worked with Ea to move course instructors toward a common curriculum and they transformed the recitations to Minnesota-style cooperative group problem solving[63,64] in 2009. The next summer, funds were secured to convert an old laboratory into a 45-person SCALE-UP classroom the next summer where instructors Ea and Eb co-taught a section of calculus-based physics in Fall 2010.

Even though the two instructors had “best case scenario” of extensive backgrounds in studio-instruction and familiarity with research-based materials, they claim it took a surprising amount of time and effort to create a SCALE-UP curriculum. Planning each day was a collaborative effort, where both instructors gave suggestions and made modifications to create something better than they felt they could have created individually. They borrowed almost all of their materials, except a Common Cents lab created by Instructor Ea, from external sources. The SCALE-UP course paralleled the traditional section with common assessment to allow students to switch back and forth so they continued use of a Halliday, Resnick and Walker textbook[69]. They modified preexisting labs to be more open-ended and incorporated *Peer Instruction*[58] and CRP problem solving[63,64], like the reformed traditional sections. 10-20% of the material was incorporated from activities instructor Ea remembers from using at NC State. He referred to the SCALE-UP website primarily for specifics about room design, not ideas for activities. He felt these activities could be incorporated in their current form. Instructor Eb included a smaller percentage of activities from Kansas State's New Studio[70] lab demos but modified them to provide more elaborate instruction and eliminate specialized equipment. They used a small number of modified Knight workbook[56] exercises to fill extra time.

After a couple successful semesters, in 2013, the department head decided to switch the Lecture-Studio model so instead of "one third of the students with 100% SCALE UP style, we would have 100% of the students with two-thirds studio style". This helped secure additional buy-in from faculty (because the workload of teaching it is comparable to a regular course) and seemed to be more cost-effective, especially since there's no more studio space available. Switching to the Lecture-Studio involved a new textbook (Knight[55] primarily for its presentation of material and the convenience of using *Mastering Physics*, not because of the workbook) but 80-90% of the SCALE-UP material carried over. The students attend two 50-minute lectures per week (which include clicker questions but are largely traditional) and two 110-minute studio sessions per week, where students do "active learning, working in small groups on lab experiments, cooperative group problem solving, interactive computer simulations of physical phenomena, and scientific modeling", according to the University of Chapel Hill website[71]. They had to modify the timing of the SCALE-UP activities to fit the new schedule and some had to be eliminated to make room for some modern physics. However, in general, SCALE-UP activities could be moved into Studio rather seamlessly and according to Ec, now with Lecture-Studio, “the pedagogy is established and that's the way we do things and we're not going back”.

**Table 1: Composite research-based reforms for SCALE-UP implementation. The letter denotes the source of information: E (educational experience in graduate school, etc.), D (Departmental colleague), C (Colleague outside institution) and L (Literature). Underline indicates that it was preexisting in introductory courses. Color denotes position on adoption-innovation spectrum.**

| | | | | |
|---|---|---|---|---|
| Abandon | Adopt | Adapt | Reinvent | Invent |

| | **NCSU** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|---|
| Peer Instruction | L | C | L | E | C | C |
| NCSU materials | | C | C | | | E |
| VPython | D | C | C | | | |
| UMN Context-rich problems | L | | | C | | L |
| UW Tutorials | L | | | | | D |
| Integrated study | E | | | | D | |
| EM Visualizations | | | | | E | |
| Kansas State New Studio | | | | | | E |
| Kansas New Studio | | | | | | |
| Thinking Physics | | L | | | | |
| Knight workbook | | | L | | | |
| Matter & Interactions | D | | | | | |

**Conclusion**

The curriculum development efforts at these institutions demonstrate that instructors' personal preferences, organizational situation and perceptions of the reform all influence their curriculum development efforts for the SCALE-UP. As Werner[72] puts it, "implementation, as a minimum, includes shared understanding among participants concerning the implied presuppositions, values, and assumptions which underlie a program, for if participants understand these, then they have a basis for rejecting, accepting or modifying a program in terms of their own school, community and class situation" (p. 62). In this study, the lack of a complete understanding between the developer and secondary implementers leads to interesting results. In most cases examined here, implementers mistakenly thought SCALE-UP was a "complete package" and did not expect to invent their own activities. Some did not realize that other research-based reforms could complement this effort. Although some instructors thought they wanted an external package created elsewhere to work well for them with minimal modifications, they ended up modifying (and in most cases, creating) materials that aligned with their personal style, preferences, and skills. Most purposefully started with a conservative curriculum to minimize unfamiliarity during the first iteration. Once they developed a curriculum with a working form, most instructors avoided making significant changes because of lack of time and they did not want to alter something that worked.

More details about these main findings are discussed below.

*For activities to be useful to instructors, they must be in a ready-to-implement form*

Instructors (at three of these institutions) repeatedly mention they embarked on the reform believing that SCALE-UP was a ready-to-implement package that could be brought to their institution, even if they did not switch to M&I[54]. Two of these institutions looked at NC State resources but quickly abandoned use when the format was too disorganized, minimal or unintuitive for immediate implementation. Instead of spending the time to modify these materials, instructors preferred to create their own. Except for Institution E, almost all of the instructors cite having to start from scratch to create a course appropriate for use in a SCALE-UP environment.  For example, Instructor Dc, recalls "blowing up" the previous course since "nothing that we had been doing that was useful and nothing anybody else is using that was useful in that direct sense".

One instructor (Aa) found that Randy Knight's textbook[55] and workbook[56] was a more organized resource that could be easily modified into the NC State format of reading quizzes, clicker questions and ponderibles.  All the other institutions found they had to piece together activities they had been doing (*Peer Instruction*[58], CRPs) then develop additional materials from scratch.  Except for the instructors that had already been familiar with PER, none of the others did an extensive search through the literature, citing a lack of time.  In one case, Instructor Ba seemed to think various reforms were mutually exclusive;

> "I guess we didn't see it as mix-n-match, like there were different schools of thought, different ways of going about it.  I think we looked at the McDermott books[59] and we thought SCALE-UP was the best, the way we're going to go and if there are things we could import from the other groups, we would do it but some of it didn't seem like it would naturally work."

Institution D consciously adapted the room design from NC State but felt that they were better off creating resources that fit the institutional, student and faculty culture to prevent pushback from faculty and students.

This has interesting implications for adoption of research-based materials.  Much of the literature on effective dissemination recommends that developers provide resources that can be adapted to an instructor's local situation[5,8,12,20].  However, this study revealed that instructors prefer activities they can implement immediately or they would rather invent their own.  None of the instructors explicitly mentioned choosing SCALE-UP because of its flexibility and adaptability. Even though it was not mentioned in interviews, the flexibility of the SCALE-UP reform enabled its use in a wide variety of disciplines and educational settings. However, the instructors in this study wanted certain materials to be immediately available and ready for implementation, especially tangible class activities. Hutchinson & Huberman[8] echoes this finding, citing a study of ERIC users[73]. The researchers found "one-stop shopping" was critical in ensuring use. If a source was listed in a bibliography and was also available at the time of inquiry, it would typically be used. Perhaps a compromise would be to keep the overarching curriculum flexible but improve access to well-organized and user-friendly suggestions for composite activities. Although the SCALE-UP website contains activities used by the development site, but it remains in a form that Institution A and B did not find helpful. In part, this is because instructors are hesitant to share activities to begin with and furthermore, there is no compensation/incentive for instructors to spend time presenting their materials to make it understandable to others. In informal conversations with faculty members, some said they would be more willing with funding and release time.

*Conservative approach to curricular change*

With the dramatic switch to a restructured classroom, most sites refrained from making radical curricular changes at the beginning, especially when it came to choosing a textbook. Institution A considered adopting M&I[54] to be consistent with NC State but the developer actively dissuaded them from making too many changes at once, a recommendation which the instructor appreciated. Instead, they chose to use a textbook that had a workbook they could modify to comprise the ponderibles, clicker questions and reading quizzes used in the SCALE-UP reform. Institution B did adopt a new textbook when implementing the reform, but chose a middle-of-the-road textbook as a compromise between radical M&I and traditional. Since they felt they had to restructure their course entirely for use in the SCALE-UP, it was not a bad time to adopt a new textbook. Unlike Institution A, whose choice of a textbook determined the form of SCALE-UP implementation, this particular choice did not seem to particularly aid or impede their reform effort. Institutions C, D and E stuck with the previous textbooks (at least initially) so they could be run in parallel with traditional courses and to help with assessment.

Changing curricula gradually allowed instructors to develop a course they would feel more confident teaching, which probably helped students feel more comfortable too. It also helped data collection efforts for studies comparing learning gains in pilot sections to traditional. While these are all good reasons to transition gradually, instructors have a finite amount of time so four sites stopped making major changes once a "working form" is established. This preserved a reform that may be more conservative than it was originally designed to be.

For example, instructors from institution A, B, C and D mention making minor adjustments in subsequent years. After developing the course, subsequent preparation primarily involved running through the slides. Even with the switch from SCALE-UP to Lecture-Studio, Institution D still directly used the vast majority of preexisting material. When instructors from Institution A and C first heard about SCALE-UP, they thought they may switch to M&I[54] after getting used to teaching in the new format. However, once they got used to SCALE-UP, they admit to abandoning that idea, primarily because of a lack of time and "laziness" since they established a working reform. The exceptions to this is

Institution B who is actively working to improve their labs (but they felt satisfied with the other parts of the class) and Institution E which took a more phased approach to appease students and faculty.

In general, a cautious approach to curricular development seems to aid sustainability but when an initial implementation attempt gets preserved, it may result in a reform that may be more traditional than intended. This echoes previous findings about the adoption of SCALE-UP at secondary site specifically[74] and research-based reforms in general[5,8,12]. Perhaps if the developers provide more initial support, adopters would feel more comfortable adopting a less conservative curriculum and avoid encountering this situation.

*The intrinsically motivated instructors in this study may be more adventurous than most*

In most of these cases, instructors decided to adopt SCALE-UP because they wanted to try something new in the classroom, not in response to a problem (except for Institution D which aimed to reduce DFW rates and increase attendance). All of these reform initiators had personal contact with the reform developer, found his argument compelling and the data he showed impressive. His message about getting students engaged in their learning, instead of sitting passively, resonated with these instructors, whether or not they had extensive and formal exposure to PER. These instructors willingly invested the time and effort to change without external incentives, like release time. Instructors C and E specifically mention how helpful release time would have been while developing the course but they were willing to endure the extra work because they believed in the cause.

All these instructors are the best-case scenarios of intrinsically motivated educators who are willing to go above job requirements to initiate a change. All of them had support from administration to build a classroom and at least have "permission" to try this. Institution D is the only one of these five cases where the department head was actively involved and provided leadership in the reform; in the other four, it was a bottom-up effort from faculty members.

While it is promising that some instructors are moved by the message and willing to initiate a change effort without external incentives, this may not hold true as the reform is moved into the mainstream. Diffusion of Innovation theory[20] describes characteristics of adopters based on their position in the adoption curve. The first 16% of adopters, Rogers[20] characterizes as innovators and early adopters who tend to be social, willing to take risks, and closely connected to scientific sources, characteristics that fit the instructors interviewed in this study. According to Rogers, innovators and early adopters both respond to the newness of an idea and are not deterred by things that may not work perfectly. However, to integrate an innovation into the mainstream, the developer must convince the early majority who tend to be conservative, cautious and avoid taking risks unless they know a reform will work.

Foote et. al.[15] estimates diffusion of SCALE-UP in physics may be at a tipping point between early adopters and the early majority. Although early adopters, like the instructors in this study, may be willing to input effort to develop a curriculum and navigate challenges, in order to spread SCALE-UP to the most hesitant majority, the developer may need to provide additional support and guidance.

**Discussion**

The results and conclusions of this study have implications for improving dissemination.

1) *Make basic activities immediately available in a useable form but build understanding of underlying principles to encourage them to adapt materials intelligently.*

Many instructors adopted SCALE-UP thinking they wanted a ready-to-go package with activities that can be immediately used in their classroom. However, even slight formatting issues prevented use of any of the developer's materials. Furthermore, the flexible nature of SCALE-UP makes it difficult to strictly adopt. In addition to providing ready-for-use sample activities, developers also need a way to promote an understanding of underlying "how-to" and "principles knowledge" that can guide implementer's efforts at developing curriculum. Unlike high school teachers, many physics faculty might have never been exposed to opportunities to create in-class activities. Thus, a more beneficial dissemination method can blend providing concrete[21] examples that can be used immediately with more abstract explanations of underlying principles. If faculty are going to modify/invent curriculum effectively, they need to understand examples of what works (details) as well as why it works (principles)[12].

Since Foote et. al.[14] estimates dissemination of SU is at tipping point between knowledgeable and adventurous early adopters and the early majority, this may become more important as the reform reaches the mainstream. These users, who tend to be less familiar with educational reform, will benefit from more structure to guide them through this process, possibly following a model similar to the one described below.

2) *Improve understanding of reform by increasing contact between disseminators and implementers.*

Hutchinson & Huberman[8] found the best single predictor of knowledge use and gain is the intensity of contact between dissemination and receivers. Effective dissemination "...involves frequent contact, some face-to-face interaction, and an exchange between dissemination specialists and participants that lasts more than a few months over time"[75] (p. 17). This sustained interactivity helps ensure the two populations have a shared understanding of the reform, which did not seem to be the case in this reform.

Considering the number of SCALE-UP sites, it would be unrealistic to expect the developer to directly communicate with each. The example of an alternative dissemination model provided below allows the developer to supervise and provide feedback to a focused group of secondary implementers over multiple days as they develop curriculum. This model could help create knowledgeable spokespeople that could aid new implementation efforts.

*3) Communication is more effective amongst more similar members*

When possible, empower other secondary users to take a role in dissemination since persuasion is often more effective amongst similar people. Rogers explains, “when two individuals share common meanings, beliefs, and mutual understandings, communication between them is more likely to be effective” [20] [p. 306]. Attempting conversation between two dissimilar people can lead to STEM faculty’s skepticism of innovations developed in different contexts or by people they perceive as dissimilar to themselves[76,77,78]. This may be especially important when trying to convince the “early majority” to try an innovation since they want to ensure a reform will work for their situation before they decide to adopt.

More importantly, we saw a knowledge imbalance can lead to expert-novice differences that contribute to misunderstandings that developers might not anticipate. Just like physics students who can resolve their difficulties better talking to a peer than their instructor, more typical faculty members who recently attempted reform may provide more relevant guidance. Since they share a similar background, vocabulary and past experiences to new users, they may be better able to predict and avoid miscommunication. The challenge for developers will be to find ways to prepare secondary users and engage them in the dissemination process.

*4) Acknowledge that reform is difficult then support instructors in building skills.*

Many innovations are presented as if significant improvements are possible by following the "simple" suggestions of the curriculum developer.[12] In the case of radical reforms like SCALE-UP, it is far from easy for faculty members to take on new instructional roles while developing curriculum and dealing with students who are not used to learning in a different way. Just as researchers recommend instructors of student-centered classrooms should anticipate and explicitly address student challenges when switching to the new mode[79, 80], developers of radical reforms should have a similar discussion with implementers. Acknowledging change is difficult can remove some of the barriers[12] between reform developers and users and encourage conversations that will promote conversations to reach a mutual understanding.

Reforms like SCALE-UP, where exact replication is not even possible, puts even more responsibility in the hands of the recipient. Instead of ignoring this reality, empower faculty to participate in the process by honoring their expertise in the classroom and at their institution. Although most of the cases documented here were bottom-up efforts by faculty champions, a top-down[81] effort may also be effective in providing additional support. Usually getting teaching centers involved helps establish a supportive community while building skills instructors need to utilize active and collaborative learning effectively.

*An example of alterative dissemination model: POGIL Core Collaborators Workshop*

An example of an alterative dissemination model that puts most of these recommendations into practice is the POGIL Core Collaborators Workshop[82]. POGIL[83] (Process Oriented Guided Inquiry Learning) groups students in teams of three or four to work on carefully designed, scaffolded problems in Chemistry or other scientific subjects. POGIL developers experimented with using Core Collaborators Workshops (CCW) to aid with dissemination and develop a community of practice[84] around this reform. They invited approximately twenty motivated participants from the same discipline (biochemistry) for a multi-day workshop with the goal of improving available materials and supporting faculty in transforming their classrooms. Participants collaborated with developers to create additional modules and assessment. During this process, the participants received feedback from developers and built confidence they needed to innovate independently while expanding resources for the larger POGIL community.

Research shows that attending one workshop usually does not lead to lasting changes in teaching[85] but the elongated exposure and feedback during this workshop aimed to build a deeper level of understanding and a supportive community to promote long-term transformation. Although a grant only provided funding for two CCW workshops, these events united people from diverse geographic locations and "provided a community and a network of support for the pedagogical shift that might not exist at their home institutions" (p. 410)[75]. The study showed that people who completed the workshop were more likely to act as leaders in other reform efforts.

**Future Work**

As this paper reports preliminary results from an exploratory study with the best-case scenario of intrinsically motivated, knowledgeable adopters. Integrating reformed teaching in the mainstream will require convincing more conservative and reluctant faculty members who may need more guidance. This paper focuses on the initial curriculum development efforts of the reform initiators in a department. To investigate what happens when the reform reaches more typical instructors, one should study what happens to curricula when hesitant faculty are required to teach the course in this manner. Since the departmental and organizational context would be similar, a study like this would allow researchers to implement the role of personal preference and sense-making for more conventional faculty.

Future work can continue to investigate how to mitigate and eliminate the divergent expectations of educational researchers and faculty that can serve as a barrier to reform. For example, how can we frame reforms to make the role of the change agent and the reformer more explicit? How can we balance research-based tools that can be implemented immediately with an adaptable basic structure? Answering these questions will require continuing the dialogue between reform developers and implementers to understand and eliminate misunderstandings between the two populations. Understanding how implementers make sense of reforms and adjust them to personal preferences and situational constraints will help develop dissemination techniques that promote usability and sustainability of research-based reforms.[86]

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[4] Redish **(**see Ref. 5**)** identifies five features of a traditional physics course in the United States. These have been modified slightly from his original list. **(**1**)** It is content oriented. **(**2**)** It has 3–4 hours of lecture and 0–1 hours of problem solving recitation per week. **(**3**)** If there is a laboratory, it will be 2–3 hours and "cookbook" in nature. **(**4**)** The instructor is active during the class session and students are passive. **(**5**)** The instructor expects the student to undergo active learning activities outside of the class section, in reading, problem solving, etc., but does not usually enforce these activities.

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## CHAPTER 5: Conclusion

Throughout this dissertation, we have seen that secondary implementers adapt SCALE-UP (Beichner 2008) according to their instructional setting, personal preferences, cultural factors and their understanding of the reform. Unlike a traditional Development & Dissemination model, where developers expect "pure adoption" and condemn modifications, this work has found that the adaptability of SCALE-UP promotes its use and survival in a variety of instructional settings.

Now let us return to the research questions posed in the introduction as a way of summarizing the main findings from these three studies.

### I. Summary of Findings

First, we asked, "How do implementers learn about SCALE-UP? What motivates the implementation?" In this study, many people learned about SCALE-UP through colleague connections and interpersonal interactions, thus these interpersonal networks may be important for future dissemination efforts. In Chapter 2, several secondary sites learned about the reform through unrelated research collaborations. In Chapter 3, we found that just as many report learning about SCALE-UP through interpersonal interactions with colleagues as mass-market channels (talks/workshops and the Internet). In Chapter 4, key initiators learned about SCALE-UP either through research/disciplinary connections or a workshop. All of them reached out to the developer for detailed implementation advice and many brought him to campus to help convince administrators. The important role of interpersonal interactions is consistent with Diffusion of Innovations theory and other work done on implementing innovative teaching in physics (Dancy and Henderson 2010, Borrego, Froyd & Hall 2010, Rogers 2003).

Many of the case study sites in Chapters 2 and 4 initiated a SCALE-UP style reform not to solve a problem but because they wanted to pioneer a new model of education at their institution. Many of the people interviewed in Chapters 2 and 4 felt compelled by the data collected at the development site and wanted to see if it would improve learning gains at their institution too. Adventurous reformers who are not afraid to experiment and try something new demonstrate characteristics of Rogers' (2003) "early adopters". The names and data from our census in Chapter 3 support that SCALE-UP may be approaching a tipping point in the diffusion curve and we anticipate that continuing to spread the reform may require appealing to the more hesitant early majority. Members of this population may need different motivation to adopt.

Next, we ask, "What factors affect the initial form of a SCALE-UP implementation?". Since SCALE-UP reforms the class environment as well as the pedagogy, one of the first steps is to renovate the classroom space, which usually requires administrative support and funding. In our census in Chapter 3, respondents rarely report lack of faculty interest as a barrier to creating this space. Interviewees report lack of discussion and funding more frequently prevent the construction of specialized classrooms. The census also verified that sites differ in their facilities and technological resources.

In addition to factors that affect structural aspects, Chapter 2 discussed cultural factors that affect implementation; not only cultural factors that arose from including an international site but also the surrounding student, faculty and institutional climate. In this chapter, apprehension about faculty and student resistance promoted more conservative second and third-generation reform efforts.

In Chapter 4, an instructor's incoming knowledge and colleague connections impacted which research-based reforms formed the basis of their curriculum for use in a SCALE-UP environment. Faculty members with a connection to the Physics Education Research community brought in resources they had used or learned about previously whereas instructors without this background either did not want to spend time looking through the literature or, in one case, did not realize that these other resources were compatible with the SCALE-UP approach.

Our third research question asked, "During use, how do users further modify the reform to fit their local setting? Why do they make changes?" Chapter 2 concluded that implementation was an iterative process and repeated modifications adapted the reform to instructor and student preference to promote gaining acceptance. With regards to curriculum development efforts in Chapter 4, almost all sites featured formed a working curriculum on the first or second time teaching the course then only made minor changes. This finding may be important to radical reform efforts because many of these instructors started with more modest curricular changes to "ease into" reform. However, lack of time in subsequent years hinders further changes especially since it seemed to work. This can lead to the preservation of a more conservative reform. In our study, there was an exception: one institution purposefully started with a partially reformed curriculum and has continued to make significant changes toward reformed instruction in subsequent years, more similar to the implementation story reported by Rogers, Keller, Crouse & Price (2015).

We found that the presence of a studio classroom (with special tables to facilitate interaction) is associated with higher levels of active learning, suggesting that the initial decision regarding the appearance and features of the classroom could impact subsequent teaching. From the literature, we know the presence of a studio classroom is not enough to improve learning gains if the pedagogy does not match the goal of the renovated room design (Cummings, Marx, Thornton & Kuhl 1999, Lasry, Charles & Witthaker 2014). Fortunately, the implementers studied in Chapter 4 seemed to know this and purposefully adjusted instructional methods in anticipation of teaching in the new space. For example, the faculty members interviewed in Chapter 4 almost universally agreed that switching the classroom environment required them to completely overhaul their curriculum to include activities to engage their students in active learning. The different classroom seemed to motivate faculty to drastically depart from traditional instructional practices.

Our final question is, "How do sites achieve sustained use of the reform?" It appears that allowing faculty members to adjust the reform according to their expertise allows them to customize and take ownership of a reform, aiding sustained use. Since modifications are inevitable and can help the survival of reform, disseminators should focus on advising sites which modifications can be made without sacrificing the integrity of the reform.

While this study did not investigate the following in depth, we also hypothesize that the presence of the studio classroom could also aid sustainability. For example our census on Chapter 2 uncovered very few true abandoners of the SCALE-UP reform. We think that investing in a classroom that stands as a symbol in support of interactive teaching may make it harder to revert to traditional methods.

**II. Implications**

**1) Leveraging interpersonal networks can improve dissemination.**

Traditional dissemination models often expect a primarily unidirectional flow from developer to implementer, due to a knowledge imbalance. However the literature suggests communication is often more effective amongst *homophilious* members of a system (who share certain beliefs, backgrounds, levels of education, socioeconomic status, etc.) (Rogers 2003). We have found that colleagues, who are more homophilious, share information about SCALE-UP and other reforms through interpersonal networks.

Future dissemination could empower and enlist the participation of successful secondary implementers to spread the word in a strategic manner. As the number of SCALE-UP sites continues to grow, it will be impossible for the developer to provide personal attention and advice to each potential implementer. More importantly, Mintrom & Vergari (1998) claim that most people considering adoption want practical information from users in similar situations to themselves who can simply explain the advantages, disadvantages and how it works. This could help minimize or alleviate some of the sense-making challenges between experts and novices (Henderson and Dancy 2008, Spillane, Reiser & Reimer 2002) and may be especially important moving the reform into the mainstream.

Another advantage of utilizing existing networks is that they can provide a supportive community around reform. We hypothesize part of the success of SCALE-UP is because setting up the classroom often requires financial and logistical support from administrators which starts departmental conversations. If dissemination utilizes preexisting professional networks as a vehicle to spread innovations, natural, more homophilious networks can provide support and longer exposure to reformed ideas as discussed in Chapter 4. Since one time exposure to reformed ideas in a workshop does not often lead to sustainable change (Loertscher 2009), diffusing information amongst existing networks could provide a venue for follow-up conversations (McLaughlin 1990).

**2) Reforms are modified and framing of the reform affects how this happens**

This study clearly demonstrates that users rarely adopt SCALE-UP as designed, especially since the lack of curriculum makes pure adoption impossible. Modifications are made for countless reasons, including personal preference, situational constraints, cultural reasons and social influence. Reform developers, and even reformers themselves, have minimal control over most of these factors but how they frame the reform can impact how faculty members put it in use. For example, certain reformers in Chapter 4 did not realize that other research-based materials were compatible with the SCALE-UP approach. Although the developer includes suggestions for modifying other reforms into the SCALE-UP approach in the literature (Beichner 2008), maybe this needs to be more explicit in interpersonal conversations and workshops.

As will be discussed more thoroughly in "directions for future research", researchers need to understand what perceptions and beliefs faculty members have about reforms so they can structure the accompanying resources accordingly. Eliminating "divergent expectations" between physics faculty and educators are probably one of the most realistic ways to remove barriers to diffusion but first researchers need to identify where these expectations start to diverge.

3) **Reformed classroom can promote use of active pedagogies and potentially aid sustainability**

This work seems to imply that classroom renovation may aid radical movements toward reformed teaching in a sustainable way, help form a community around the reform and stand as a physical symbol of change that might attract other users. Work is currently being conducted to see how significantly these factors affect implementation efforts at SCALE-UP sites but developers of other research-based materials may want to think about how they could frame their reforms to achieve similar ends, if structural changes are not explicitly required. How can dissemination methods create a community around a reform effort and conversations between faculty and administrators? How can reformers create symbols of change that attract the attention of other potential users and crystallize reform efforts? We hypothesize the classroom stands as a physical symbol of change that makes it harder to revert back to old methods and attracts other potential users. While this result appears promising for ensuring the spread and survival of SCALE-UP, how can we make other reforms similarly visible? Wieman, Perkins & Gilbert (2010) provides some examples for implementation of Science Education Initiatives at their institution.

## III. Limitations And Directions for Future Research

Except for Chapter 3, which presents a quantitative summary of the large-scale census of the use of SCALE-UP amongst higher education institutions in the United States, this work primarily relies on qualitative case studies. In order to get qualitative depth, we had to focus our sample. While drawing conclusions based on a small number of sites restricts the generalizability of results, these sites were chosen for a reason and this exploratory work creates avenues for further research. Future work can broaden this sample.

Because of the selection criteria, most of the featured cases represent the best-case scenario of adventurous, early reformers who adopt this novel way of teaching willingly, without external pressures or explicit problems to solve. Chapter 3 estimates that the dissemination of SCALE-UP might be at the tipping point between these intrinsically motivated early adopters who appreciate the novelty of a new reform and a more hesitant early majority. Since early adopters are more likely to embrace a radical discontinuity from traditional teaching, to champion the cause against local resistance and to persevere through inevitable glitches (Moore 2002), the transition to more typical instructors may not happen easily or naturally. Future work should investigate how more "mainstream" instructors navigate this process; what motivates them to attempt a reform? What kind of support do they think they need? How do they use reform materials? How does the enacted use of the reform compare to colleagues (in the same departmental environment) who have backgrounds in PER? What kind of training could alleviate issues related to a lack of expertise?

Whether or not researchers are concerned with changing the behaviors "mainstream instructors" specifically, a fruitful avenue of dissemination research could continue to investigate the sense-making process of reformers about a given instructional innovation. In the exploratory case study in Chapter 5, instructors decided to implement SCALE-UP without having a complete understanding of their role in the reform effort. This could have created an impenetrable barrier to implementation if faculty members were not motivated to put in the effort of adjusting and developing materials themselves. Many challenges and constraints to reform efforts (funding, administrative support, facilities) are out of the control of disseminators but reform developers can affect how they frame and market their materials. More work must be done to understand what faculty members want from reform developers, how much effort they are willing to invest and how clearly they understand the messages from researchers to minimize divergent expectations. Investigating and mitigating misinterpretations between these two populations can have a significant impact on improving the user friendliness and usability of research-based materials.

## CHAPTER 5 REFERENCES

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## APPENDIX

**APPENDICES**

**Appendix A**



**Appendix B**



**Appendix C**

## Appendix A: Chapter 2 IRB Application

Institutional Review Board for the Use of Human Subjects in Research
REQUEST FOR EXEMPTION (Administrative Review)
GENERAL INFORMATION

1. Date Submitted: October 24, 2013
2. Title of Project: Factors underlying the adoption of a university physics reform across three generations of implementation
3. Principal Investigator: Kathleen Foote
4. Principal Investigator Email: ktfoote@ncsu.edu
5. Department: Physics
6. Campus Box Number: 8202
7. Phone Number: 860-989-2910
8. Faculty Sponsor Name if Student Submission: Dr. Robert Beichner
9. Faculty Sponsor Email Address if Student Submission: beichner@ncsu.edu
10. Source of Funding (Sponsor, Federal, External, etc): Data collected under the EAPSI Summer Fellowship

If Externally funded, include sponsor name and university account number: OISE-2013
RANK: Student, PhD

**Project Description**: Describe your project by providing a summary and answering the requests for information below.

1. Project Summary. Please make sure to include the purpose and rationale for your study and a brief overview of your methods.

SCALE-UP "Student-Centered Active Learning Environment with Upside-Down Pedagogies" is a reformed pedagogy and classroom design first developed for large enrollment university physics courses at North Carolina State University but is currently in use at over 250 institutions worldwide in over a dozen subject areas and a variety of institutional types. This exploratory case study examines how the reform has evolved over three generations of implementation, from its development site at NCSU to one of the most well known implementations at MIT to an international site in Singapore.
Studying how the implemented reform adjusts to different cultures, student populations, instructors, and institutions has implications for improving the adoption process of other research-based reforms worldwide. Data and results may inform the development of resources that could help researchers, curriculum/professional development developers and future implementers better support sustainable and effective use of research-based pedagogies.
Faculty (instructors and administrators) who are involved in implementing the SCALE-UP-like reform are the main subjects of this study. Participation in the study is entirely voluntary. Upon volunteering for the study, faculty members will undergo a 1-2 hour interview scheduled at a mutually agreed upon time, either in person at their institution or on Skype. These faculty members can agree to have their class observed 1-5 times during the semester and can agree to pieces of the interview reported non-anonymously.
The instructors who elect to have their classes observed will allow the PI to sit in on their class but these will not be audio or videotaped. The classroom observations are meant to help characterize the implementation at an institution so besides time logs and field notes, no direct data will be captured.

2. Describe your participant population. This includes age range, inclusion/exclusion criteria, and any vulnerable populations that will be targeted for enrollment.

5-10 faculty members and 2-5 administrators will be involved in interviews.
Faculty members that were instrumental in bringing active learning introductory physics courses to their university, administrators involved in the decision-making and/or instructors who have taught in these classrooms are eligible for an interview.
Both faulty members and administrators who agree to participate in the study will be asked to read the consent form. Three participants Peter Dourmashkin, John Belcher and Bob Beichner will be requested to allow researchers to use their identity non-anonymously in publications because of their key contributions to developing the reform that are already widely known and made public in the literature.

3. Describe how potential participants will be approached about the research and how informed consent will be

obtained. Alternatively, provide an explanation of why informed consent will not be obtained. Include a copy of recruitment materials, such as, scripts, letters of introduction, emails, etc. with your submission.
The PI will e-mail potential participants (faculty members and administrators involved in implementing or teaching using SCALE-UP style instuction) introducing themselves, the project and the objective of the interview. Before they are interviewed, they will read and sign the consent form. I will offer faculty the opportunity to be indentified in publications (which is completely voluntary). After they complete the interview, they will be given the opportunity to opt out of the study. Otherwise the audio data of the interview will be retained until it is transcribed,

Faculty who are currently teaching SCALE-UP style classes can elect to have their classes observed.
4. Describe how identifying information will be recorded and associated with data (e.g. code numbers used that are linked via a master list to subjects' names). Alternatively, provide details on how study data will be collected and stored anonymously ("anonymously" means that there is no link whatsoever between participant identities and data). Describe management of data: security, storage, access, and final disposition. 1) Interview of faculty members will be audio recorded and transcribed. Any identifiers created during data analysis and used in reporting will be randomly assigned to distinguish one interviewee from another. These serve a research purpose there are no risks to compromising subject anonymity. Individual responses from the faculty interviews will be described.
2) The only data collected from the classroom observations will be a time log of activities and general field notes about levels of engagement, types of questions asked and general classroom dynamics. Classroom observations will be only reported as an aggregate overall characterization of the implementation.
All audio data will exist in electronic form, stored on a secure PERD group server with access restricted to members of the PERD group. As the amount of data accumulates on the server, data may be transferred to external hard drives secured in the PERD observation room by lock and key. Additionally, the drive itself will be password encrypted to secure the data against loss and theft. PERD group members are allowed to use the data and its analysis in future research projects. All data may be kept indefinitely.

**5. Provide a detailed (step-by-step) description of all study procedures, including descriptions of what the participants will experience. Include topics, materials, procedures, for use of assessments (interviews, surveys, questionnaires, testing methods, observations, etc.).**
Recruitment of faculty members and administrations will be entirely voluntary. Faculty users of SCALE-UP style instruction or administration who were involved with the decision-making regarding SCALE-UP will be e-mailed or asked in-person whether they would like to be interviewed to discuss their experiences with the SCALE-UP reform. These e-mails will be sent prior/during site visits. The PI will be available via e-mail, telephone or Skype to further review the study, answer any questions and/ or address any concerns. Faculty will then have the option to opt-out of the study or participate and sign the consent form. To be included in the study, these faculty members will need to be interviewed and the ones who are currently teaching can elect to have me observe their introductory physics active learning classrooms.
Interviews with faculty members will either take place in person at the institution under study (MIT, NCSU and SUTD) or on Skype. The PI will have the faculty members sign the consent form them audio record the interview on site. The subjects are also informed that in order to help maintain their anonymity and those of specific people mentioned during interviews, these names will be assigned pseudonyms during transcription and audio records will be deleted after they are transcribed. Data will be stored on a secure server in a room under lock and key. The interview of the faculty members will take approximately 1 hour.
During classroom observations, the PI will introduce themselves and the purpose of the observation and tell the class to complete the same activities as they would if they weren't being watched.
During the classroom observation, the PI will write down time logs of the classroom activities and take notes about general classroom engagement and types of interactions. These observations are just to get an overview of the implemented reform- they will not be audio or video recorded. No direct quotes will be written down from class observations. No time beyond standard class time will be required of the students, besides the few minutes of the PI introduction before the classroom observation.
6. Will minors (participants under the age of 18) be recruited for this study: No

7. Is this study funded?
 a. Is this study receiving federal funding? Data was collected under NSF EAPSI 2013 fellowship (OISE-13)
 b. If yes, please provide the grant proposal or any other supporting documents.
8. Do you have a conflict of interest or significant financial interest in this research?
No
a. What does your plan include for managing this conflict of interest and is it being properly followed?

**Appendix A: Chapter 2 Sample Interview Questions**
**Administrators**
1. Can you tell me a little bit about the educational backgrounds that lead you to being the head to the physics department?
2. What were your goals as department head/dean/provost?
3. When and how did you first learn about SCALE-UP?
4. First impressions?
a. Did you think it would be a good fit for NCSU with regards to student, faculty culture, etc? Why or why not?
5. Did the department have any history with innovative courses or pedagogies like SCALE-UP ?
6. As department head/dean/provost, what did you regard as your primary responsibility with relation to requests like these?
7. When consent was granted, was it conditional? What was needed to happen to make the change permanent?
8. From your perspective, what were some of the biggest challenges/obstacles during implementation?
9. What were faculty reactions? Student reactions? Reactions from higher administration?
10. What do you think is the future of SCALE-UP?
**Key implementers**
1) Where did the idea of SCALE-UP originate? What tangible benefits were you hoping to achieve with this reformed approach to teaching?
2) What did you have to do to turn this idea into a reality?
3) Was the department supportive? What helped persuade non-believers that this was a good idea?
4) When starting to plan and build your active learning classrooms, what external guidance did you receive and which references did you consult?
5) How would you characterize the student population at your institution? How did this affect the design and execution of SCALE-UP?
6) How does the personality as an instructor affect the execution of SCALE-UP?
7) What were the biggest challenges to first implementing SCALE-UP? How did you overcome them?
8) How has the reform evolved since it first began?
9) How did you get the word out about SCALE-UP? How active and formal was this dissemination?
10) When other institutions want to implement SCALE-UP, do you expect them to implement it as is? Why or why not? Do you tell them this explicitly?
11) How was the connection with MIT initiated? What kind of support did they request and what did you provide?
12) How much continued contact with secondary implementation sites?
202
13) What do you see as the future of SCALE-UP reform and dissemination process?

How do you anticipate it will evolve in the next 5-10 years?

**Other faculty members/instructors in the department:**

1. What is your educational background? Do you have any experience teaching with interactive pedagogies like SCALE-UP?
2. Why did you want to try teaching using these methods?
3. How much professional development and training was provided here?
4. When you first went to MIT, when you first heard about this mode of teaching, what were your first impressions?
5. What were your goals for teaching with this instruction? What did you hope your students would get out of it?
6. Did you think it would be a good fit for the students and/or faculty culture at your institution? Why or why not?
7. I'm assuming most of your students came from backgrounds that they were educated in traditional ways. Have you noticed them have a hard time adjusting?
8. What key aspects of the course organization or pedagogy are required to run this teaching effectively?
9. Have you attempted to collect data to test the efficacy of this approach? Does it seem to be working? Why or why not?
10. How has the reform changed since you first implemented it?
11. How do you expect the innovation to evolve in the future?

## Appendix A: Chapter 2 IRB Approval

North Carolina State University is a land-grant university and a constituent institution of the University of North Carolina

**Office of Research and Innovation**
Division of Research Administration

NC STATE UNIVERSITY

Campus Box 7514
Raleigh, North Carolina 27695-7514

919.515.2444 (phone)
919.515.7721 (fax)

From: Deb Paxton, IRB Administrator
North Carolina State University
Institutional Review Board

Date: June 11, 2014

Title: Factors underlying the adoption of a university physics reform across three generations of implementation

IRB#: 3829

Dear Ms. Foote,

The activities in the research named above have been determined to be exempt from the policy as outlined in the Code of Federal Regulations (Exemption: 46.101. b.2). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review. This approval does not expire, but any changes must be approved by the IRB prior to implementation.

NOTE:

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU projects, the Assurance Number is: FWA00003429.

2. Any changes to the research must be submitted and approved by the IRB prior to implementation.

3. If any unanticipated problems occur, they must be reported to the IRB office within 5 business days.

Please forward a copy of this letter to your faculty sponsor, if applicable. Thank you.

Sincerely,

Deb Paxton
NC State IRB

## Appendix A: Chapter 2 Short Form Coding Scheme

| "Directly" related to implementing reform | | Backdrop to Implementation | |
|---|---|---|---|
| **Classroom** | | | |
| Student Engagement | StuEng | Student Characteristics | StuChara |
| Class Community | Comm | | |
| Student Feedback | StuFdbk | | |
| Instructor Feedback | InstFdbk | | |
| Room geometry | Room | | |
| Policies/Procedures | PolPro | | |
| Resources | Resource | | |
| Instructor Characteristics | InstChar | | |
| **Departmental** | | | |
| Collegue Opinions | CollOp | Faculty Culture | FacCul |
| Departmental Support | DeptSup | Past Change Efforts | Past |
| Data | Data | Content/Curricula | ConCurr |
| Funding | Funds | | |
| Faculty Champion | Champ | | |
| **Institutional** | | | |
| Internal Professional Development | InProfDev | Core requirements | Core |
| | | Faculty Responsibilities | FacResp |
| | | Image | Image |
| Culture | | | |
| Other Implementation | OthImp | Technological Advances | Tech |
| | | Educational Research | EdRes |
| | | Geographical Culture | GeoCul |

| Implementation | |
|---|---|
| Agenda setting | Agenda |
| Matching | Match |
| Redefining/Restructing | Redefine |
| Clarifying | Clarify |
| Routinizing | Routinize |

**Appendix A: Chapter 2 Coding Scheme**

<table>
<tr><td colspan="2">Classroom: statements regarding factors that influence classroom dynamics, activities and interactions for one section of the course, including students and their instructor. For example, the instructor has the freedom to choose activities and how to present them to his students. Room design, logistical issues and class structuring that affect class sessions also fall under this category</td></tr>
<tr><td>Student characteristics<br><br>(StuChara)</td><td>Personality, preferences, study habits of students at the institution (these may be university-wide student characteristics… just NOT "kids these days" type statements)<br>o "Their pattern was to take a lot of courses, not go to lecture and do the problem sets, cram for the exams, get the units credit and get into really interesting undergraduate research in the field that they wanted to go and electricity and magnetism was an obstacle that had nothing to do with it"<br>o "I think teaching freshmore year is a transition year, some of them are still in 'high school style' learning habit. Do not know how to manage time… these are very challenging for us"<br>NOT characteristics attributed specifically to cultural differences in geographic origin (culture -> geographic culture)<br>NOT technological influences (culture -> technological advances)</td></tr>
<tr><td>Student engagement (StuEng)</td><td>Statements about how students interact with activities, with their peers and with their instructors, including structured groupwork during class. Statements about whether students are interested and participating in the class fall under this category. Statements about groupwork and class activities fall under this category.<br>o "With SCALE-UP, there's no place to hide- you're on duty the whole time."<br>o "Sometimes the better students may be bored so we try to encourage them to do peer to peer learning and teach their peers"<br>NOT statements about how the room influences interactions (classroom->room), NOT statements where students are providing feedback whether or not they like the activities (classroom->StuFdbk)</td></tr>
</table>

| | |
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| **Class Community (Com)** | **Efforts to build a classroom community and support students primarily outside of class, maybe by provide additional academic or study resources to students, including those who may be struggling. This code is more about building a supportive learning community, NOT about building research collaborations (or other relationships that don't improve the educational experience for students).**<br>o "So that's one of the very nice features of SCALE-UP that you actually get to know some people and it's one of the benefits, especially during the first year, to be placed in a small group. You don't feel like you are a number in a huge crowd."<br>o "So that math review nights. They can't believe that we do a review night from 9-11 PM and the reason we do it then is because they have a lot of other activities- sports, dinner, other classes and them they are free from 9-11. That's actually prime time"<br>**NOT** statements about specific interactions/groupwork during class (Classroom->StuEng) |
| **Student feedback**<br><br>**(StuFdbk)** | **Student comments on specific activities, aspects of the pedagogy or classroom environment that they had feelings or opinions about**<br>o "As we know that the students tend to like MIT materials because they are done by very good professors who are also very experienced"<br>**NOT** observations of students where an instructor needs to infer what they are thinking or feeling (classroom->instructor feedback) |
| **Instructor feedback**<br><br>**(InstFdbk)** | **Lessons learned or insights gained from the instructor trying SPECIFIC strategies, techniques or activities. Anecdotal evidence about the effectiveness of trying a specific small activity (without an official study being done or data collected) falls under this category**<br>o "That was just the slow evolution of faculty members trying things and putting things in that they liked"<br>o "One of the things about the camera, after they did a problem and were ready to project what they did and show it to everyone else. That was only marginally useful- it wasn't really great."<br>**NOT** data that proves the general SCALE-UP-like overall approach was ineffective/effective or data demonstrates a need for a change and a reformed pedagogy (department->data) |

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| **Room geometry**<br><br>**(Room)** | **Aspects of the physical classroom and equipment that influence instruction, interactions, etc.- for example, round tables, whiteboards on walls/tables and projection capabilities. Discussion about how the room geometry influences interactions falls under this category.**<br>o "One of the things about the studio formula is that each table had a projector and a board to work on. And it always bothered us that all 9 students would get up to their one board and two or three would work on the problem and the other 6-7 were not paying attention, chatting or doing other things"<br>o "One of the things about the camera, after they did a problem and were ready to project what they did and show it to everyone else" |
| **Policies/procedures (PolPro)** | **Administrative or organizational tasks within the classroom, grading and attendance policies for the course, general feasibility of running the course (including class size). Organization of the course with regards to the daily flow of topics as well as how topics are sequenced over the semester.**<br>o "We originally had undergraduate TAs who graded homework. And they came in, they got the homework and they brought it back. But in back, they didn't do that so it was a huge paperwork mess and homework was missing"<br>o "So how we really try to do this without wasting time is that in the cohort classroom, we do 15 minutes lecture, concept questions which is hands-on for about 45 minutes and then we close it, no more then move on to a new thing."<br>**NOT** talking about assigning specific activities or setting up/executing groupwork (Classroom ->StuEng) |
| **Resources (Resource)** | **Primarily discussion about staffing (including status of the TA), time and (general) space allowances (including how much time the class meets but also time required for planning). General complaints about "no space for the classroom" and "too much faculty preparation time required" would fall under this code**<br>o "it ended up being so much work that we realized that no one else would be crazy enough to do it. So we broke it apart." |

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| | ○ "The most difficult thing is MIT has a strong team of technical staff so the instructor doesn't have to do much. For us, we see that our faculty has to do much more without technical people so that is the most difficult part"<br>**NOT** talk about general financing (department->funding), NOT discussion about SPECIFIC classroom elements (classroom->room) |
| **Instructor Characteristics (InstChar)** | **Discussion of personality/characteristics that aid or impede the implementation of the innovation. Openness to new methods potentially stem from a discontentment with traditional pedagogy (or if an instructor talks about how they were influenced by past events)**<br>o "So it kind of caught on and caught on around the country but you have to be willing to abandon ideas about the lecture format up front and that's pretty hard if you've been doing it successfully for years.."<br>▪ **"**Students should be challenging you "why do I need to know this?" which is a wonderful question but not all faculty respond well to that."<br>**NOT** commenting on the effectiveness of something they tried while using the innovation (Classroom->instructor feedback) |
| **Departmental:** policies and practices controlled by decisions at a departmental level that affects all physics courses. This includes the opinions of colleagues and attempts to sway their opinions with data, funding, etc. | |
| **Colleague opinions (CollOp)** | **Attitudes/thoughts of departmental colleagues surrounding the use of the innovation SPECIFICALLY (why or why not it may be a good idea, whether they would be willing to try it)**<br>○ "And people opposed to TEAL, thinking it's not necessary to change the traditional ways of teaching because it worked for hundreds of years"<br>○ "Older faculty didn't even like the concept of the class"<br>**NOT** decisions made by department heads or chairs who speak for the department as a whole (department-> departmental support) |
| **Faculty Culture**<br><br>**(FacCul)** | **General atmosphere of the departmental faculty culture (independent of a stance on this issue)- common characteristics, attitudes, behaviors**<br>▪ "Also, teaching is a different culture in high school as you know. Teachers are more used to sharing their classroom, having visitors" |

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| | **NOT** institution-imposed expectations/requirements of faculty members (Inst.->FacResp) |
| **Departmental support**<br><br>**(DeptSup)** | **Department decisions, often made by heads or chairs (or deans or provosts… any superiors at the institution), who represent the department's official stance on an issue**<br>○ "The department was incredibly supportive during the trial and error period. And if they weren't support, it would have shut down and we would have never gotten through the trial phase"<br>**NOT** feelings made by isolated departmental colleagues that aren't endorsed by the department as a whole (department->colleague opinions) |
| **Data (data)** | **Studies done and data collected within the department, related to how well the reform is working. This may be data regarding the problem the reform intends to fix (ex. low attendence, high retention rates) or data that monitors how well the reform is working (ex. learning gains, retention rates). This data can be anecotal or qualitative as long as it's discussing how well the reform is working**<br>▪ "It turns out that in TEAL, the women do much better. There are many more women in the top percentage than men"<br>**NOT** results from education research studies done elsewhere (culture->education research)<br>**NOT** data that was primarily used for the instructor's own personal use to improve the classroom experience (classroom->instructional feedback) |
| **Content/curricula (ConCurr)** | **Departmental content development efforts- for example, labs, resources and other activities shared between all physics sections. Also, this includes discussions regarding the topics covered and skills that should be mastered/goals of the physics curricula.**<br>○ "So a lot of our pedagogy is to get them ready so when they are doing their problem sets to be able to get a quality learning experience out of it"<br>○ "Once John demonstrated that we were getting good learning gains, we had the issue of time and topics. One of the things faculty would constantly say is that we were watering down the course" |

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| | **NOT:** Universisty-wide requirements of graduates (for example, university wide grading procedures and core course requirements) (Institution->Core), **NOT:** How various topics are arranged or how daily classes are run (classroom->polpro) |
| **Past change efforts (Past)** | **Departmental history regarding trying innovative instructional strategies that predate and pave the way for the innovation. This may include past courses offered by the department that include active learning or inquiry-based, etc. These may courses that instructors worked with in the past that might have influenced them.**<br>o "But the program that is really quite interesting is the Integrated Studies Program, ISP. This is a technology and science course that looked at the way of thinking about many ideas. But the thing that Arthur was really passionate about is that you don't lecture students- you let them learn through workshops and examples."<br>**NOT** pre-SCALE-UP data that creates a need for reform (Department->Data)<br>**NOT** physics education research techniques used outside the institution (culture->EdRes) |
| **Funding (Funds)** | **Mentions of funding as a primary factor impacting the innovation (ex. "too expensive" to redesign the room, earning a grant to fund the reform effort)**<br>o "And at that point, John Belcher was very interested in education research and trying to modify how introductory physics was taught at MIT. So he got a grant from the Dardoff foundation and a whole bunch of other with money" |
| **Faculty Champion (Champ)** | **This refers to a specific faculty member devoted to ensuring the survival of the innovation at the institution. They typically serves as a spokesman to defend the innovation to colleagues, the department and/or the institution. They also may involve promoting the use of the innovation elsewhere but this effort is secondary to ensuring the continued use at their institution. As defined in the literature, "a champion is a charismatic individual who throws his or her weight behind an innovation, thus overcoming indifference or resistance that the new idea may provide to the organization- contributes to success"** |

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| | ○ "So we scaled up in 2003 and Eric took over the leadership of the course for three years and I took over the development of 8.01 course and John did two things. He started stepping back, he still taught but he was fighting the battles of making sure TEAL survived departmentally"<br>○ (After the presentation,) "some people who had been quite skeptical asked, "how can I do some of this stuff in my class?" so that seemed to make a substantial difference."<br>**NOT:** an instructor who anecdotally reports observations about their experiences- (classroom-> instructor feedback) "faculty champion" code requires a more pressing agenda |
| **Institutional:** school-wide policies, procedures, actions or expectations | |
| **Internal Professional Development (InProfDev)** | **Teacher, staff, and/or teaching assistant training offered within an institution. Even departmental staff training programs (including teacher assistant training) fall under this code**<br>○ "We had an undergraduate TA training program that wasn't very good. We need a better training program and we will do that. Probably next term"<br>**NOT:** professional development offered at workshops or other institutions (culture-> external support) |
| **Core Requirements (Core)** | **Specific institute-wide policies including rules about university-wide grading, core curricula, expectations or qualifications for graduates. This includes interdisciplinary projects required of all students.**<br>○ "At MIT, every student has to take physics."<br>○ "Faculty from other departments were complaining that the students who took the first year physics from the department weren't learning physics. They would come into mechanical engineering courses or astro courses and not know the fundamental concepts"<br>**NOT:** Specific physics content covered WITHIN the physics course (departmental->content/curricula) |
| **Faculty responsibilities (FacResp)** | **University-wide expectations for what makes a good faculty member- this may include having a strong research background, ability to get tenure. Statements about how collegues may view a faculty member based on perceptions of how well they fulfill their roles and responsibilities fall under this code** |

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| | o "People were pretty comfortable with the idea that we should make another hire in this area and that was Bob. That was pretty interesting because he didn't have a pure physics research background... People got the sense that he was an entrepreneurial person who may come up with interesting ideas and take the program and push it as a grad program.<br>o "The goal of the faculty member is to sift and synthesize and put an argument together and it's up to the students"<br>o "Faculty were told not to be good teachers because if you were, it's obvious you are putting too much time into it."<br>**NOT** statements specifically related to their use of the innovation (Dpmt->CollOp) |
| **Image (Image)** | **Institutional mission, culture and/or atmosphere that influence expectations for what happens at the school. This includes press releases and publicity regarding the use of the innovation at the institution**<br>o "Part of the MIT culture is that it is a problem set culture and students have the expectation that they'll do their learning on the problem sets"<br>o "We're a new school trying new things and I think that can create a very different atmosphere and culture regarding education" |
| **Culture: everyday and academic backdrop beyond the institution, including nationwide and global trends or factors** | |
| **Technological advances (Tech)** | **Technological changes and advances that impact society- for example, social media, internet accessibility. Changes in student characteristics or educational trends directly attributed to shifting technologies DO fall under this code.**<br>o "There's a lot more information generated as technology advances and as communication devices communicate what instantaneously happens all over the world so people are more informed and people have more easy access to information and knowledge so the education system has to change in some way"<br>**NOT:** a specific piece of technology being used in the classroom (classroom->room design) |

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|---|---|
| **Other implementations (OthImp)** | **Awareness and/or support from other SCALE-UP/TEAL/co-hort implementations (including in other departments at an institution). This includes learning about the innovation from another insititution using it. This also includes receiving curriculum, materials, guidance from external sources or other institutions USING THE INNOVATION. This may include professional development offered outside the institution (this may include a workshop with detailed information on how to teach using SCALE-UP)**<br>o "When finally MIT did do it, we suddenly empowered all these other universities and said 'Look. If MIT is doing this, why aren't we doing it? Because we're not a research university and we have a lot better teachers and we can do a better job at it than MIT."<br>o "Peter brought me (an SUTD instructor) to the TEAL classroom itself and told me a lot of details about how the TEAL classroom was run, I was going to bring back the experiences that Peter kindly shared with me and try to emulate as much as we could to keep the students as close to the TEAL experience at MIT as possible"<br>**NOT** direct, personalized support for active learning efforts (culture->external support)<br>**NOT** seeking out and speaking to an educational researcher after reading their work (Cuture->EdRes) |
| **Education research (EdRes)** | **Findings from education research conducted outside the university that might rationalize an instructional decision (research that may not be on the innovation itself). References to cognitive science, educational psycology or specific physics education researchers and any influential research not directly related to the innovation fall under this category.**<br>▪ "Then Rich Felder who is retired from here, did some work on learning styles so I paid quite a bit of attention to that and active learning in general."<br>**NOT** a direct, in-person working collaboration with an educational researcher (Culture->ExColl) |
| **Geographic culture (GeoCul)** | **If certain student/teacher characteristics/tendencies are directly attributed differences in behaviors or personalities are attributed to growing up, being educated, etc. in a specific geographic place. This includes cultural stereotypes.** |

| | |
|---|---|
| | ○ "In Singapore, out students are a little bit shy and a little bit quiet compared to MIT students. I think we combine the conventional big lecture together with TEAL (cohort) is a nice balance point, which works very well to our students here" |
| **Educational Trends (EdTrends)** | **General trends in higher education. This includes nationwide or global calls to reform STEM education, improve recruitment, retention, etc. These trends are pretty generic and should be widespread enough that ordinary citizens are probably aware of, NOT related to specific research developments or technological advances**<br>▪ **"**But more and more people are interested now because I think that's because of the changing styles of instruction." |
| **External Collaborations (ExColl)** | **If informal encounters and meetings initate an interest in PER or active learning (not SCALE-UP specifically). This can include collaborations on non-SCALE-UP projects or conversations with people from other institutions.**<br>"I was working with Bob and I was down at NC State. We were, he's got some interest in visualizations, I do too. I do a lot of animations and stuff and I was talking to him about that." |

## Appendix A: Chapter 2 Sample Coding

| Transcipt | Class | Dept | Institut. | Culture |
|---|---|---|---|---|
| *So where did the idea of SCALE-UP originate?* I was team-teaching a course that was integrated physics-engineering and chemistry. | | Past | | |
| It was a wonderful course. | | Past | | |
| Probably the most interesting, rewarding teaching I've ever done. | InstChar | | | |
| The students were learning all kinds of stuff because they were in the same groups across all of the classes but the faculty were sitting on each other's classes. | InstFdbk | | | |
| We were meeting outside of class, we were designing activities that would span all the courses | Comm | | | |
| it ended up being so much work that we realized that no one else would be crazy enough to do it. | Resource | | | |
| So we broke it apart. We took the integrated aspects in the introductory engineering course then returned the other classes to their standard content. | | Past | | |
| Which meant I had to go from the class size of 36 in this experimental thing to classes of 100. | PolPro | | | |
| The problem was that we've been using pretty much every kind of research-based pedagogy on these folks that we could find- collaborative learning, theories and all that stuff. | | | | EdRes |
| And I didn't want to go back to lecturing because I knew how much better, | | | | EdRes |
| I had seen how much better, how much more effective it was. | InstFdbk | | | |
| So the question was, how do you take research-based methods that were designed for much smaller classes with a lot more faculty, in some cases, 24 students and three teaching people. | | | | EdRes |
| We couldn't do that so the question was, how do you scale-up it up, so that's where scale-up came from. | Resource | | | |
| We first tried to do it in a standard lecture hall | Room | | | |
| because I was told by the department head that's all that I would have unless I brought in external funding. And we didn't have outside funding at first. | | Funds | | |
| But they were re-vamping the lecture hall from the paddle, wooden seats to anything I wanted, but I had to keep the stadium floors. So I said, let's put in long tables and alleys along the floors so I can get to every student. | Room | | | |

| | | | | |
|---|---|---|---|---|
| And they left out the aisle in the center, which meant it wasn't much better than a traditional lecture. | Room | | | |
| It was a disaster as far as teaching goes- students did not want to do the activities | StuEng | | | |
| because they said it was childish. | StuFdbk | | | |
| They couldn't get up to get equipment, they couldn't get up to write on the whiteboards | Room | | | |
| so it was just a disaster so I decided to just re-vamp the whole thing. | InstFdbk | | | |
| And at that point, I had gotten funding so that paid to have people, some research, graduate students, Duane Deardoff and folks like that would sit in the class and the lessons were videotaped | | Funds | | |
| The pilot class had 6 tables of 9, 6-foot diameter tables for awhile because round tables weren't easy to come by- we just borrowed them from a hotel for awhile then we finally bought them. | Room | | | |
| We found out eventually that those tables were too small. We had done some different round table sizes within the integrated class and we had found that 7-foot diameter tables actually worked best. | InstFdbk | | | |
| *Was the department supportive? If not, what helped persuade them?* Outside funding made all the difference. | | Funds | | |
| Until that, I couldn't do anything and after that, and in fact, my guess is that, the department head figured I wouldn't get funding for it because of what he said. | | Funds | | |
| This was back in the day when NSF required matching funds, which was actually pretty much of a hassle. So what he said was, if we got funded, the matching funds would be to buy furniture and I said "ok" then we got the funding so he had to buy the tables | | Funds | | |
| and I got another grant from Hewlett Packard to buy the laptops. So there you go. | | Funds | | |
| But the faculty overall fluctuated. Before anything started, I surveyed them and a sizeable fraction, the majority of them said they'd be interested in trying this out. Once it was in operation, not nearly as many were interested on it. | | CollOp | | |
| When I gave presentations about it, I had to give two different presentations. One when I was first starting and one when it was tenure decision time. | | | FacResp | |
| The first one, I spent too much time explaining why it worked in terms of the educational psychology and social constructivism, Vygotsky, and all that stuff. | | | | EdRes |
| That was not at all the way to do it. They were not at all impressed. | | CollOp | | |

### Appendix A: Chapter 2 Sample Classroom Observation

| | |
|---|---|
| **Date and Time:** Thursday, April 11, 2013, 9-11 | **Class:** Introductory E&M |
| **Observer:** Katie Foote | **Topic:** Introduction to electric circuits |

Contextual background:

| |
|---|
| **Student population** (number, gender, ethnicity, etc.):<br>▪ Seems like women are grouped together (~40% of the class)<br>▪ Most students appear to be ethnic minorities (maybe ~60% Asian)<br>▪ Morning class supposedly does the best on the tests |
| **Background about instructor (and TAs):** Cosmologist is main instructor (second time teaching this course), one graduate TA, 3 undergraduate TAs<br>Instructional technology assistant who helped with projection and demos |

Physical classroom set-up:

| |
|---|
| **Tables (size/shape) and seating arrangement:**<br>11 round tables of 9 students (~100 students), 1 desktop per group of three |
| **Whiteboards & Projection capabilities:**<br>▪ Instructor has a microphone that he passes to students asking/answering questions<br>▪ Uses projector for powerpoint and to project himself deriving things on the whiteboard |
| **Lab equipment storage:**<br>▪ Nearby storage room with lab equipment where the instructional technology assistant is based out of<br>▪ Besides the pre-assembled demo, no lab equipment was used today |
| **Computer accessibility & other technology:**<br>▪ 3 computers per table (one per group), ~25% of students bring their own laptops and these students tend to be more off-task |

| Time | Observation | Notes |
|---|---|---|
| 9:00 | Introduces visitors, review transformers and reminds students of experiments from last class | |

| | | |
|---|---|---|
| 9:17:55 | Conceptual clicker question- how would a residential transformer look? | Instructor reads question, counts down ~5 seconds to get first attempt at an answer, asks table 3 a question to identify whether you want higher voltages in your house, table 5 gives correct answer and he elaborates on the correct reasoning<br>**Real world application** |
| 9:21 | Why transmit power at higher voltages… why not transmit at super-high voltages? | Calls on table 9- they answer "breaks down the air" but instructor doesn't ask for much elaboration |
| 9:25 | Projects himself deriving an expression for power | |
| 9:31 | Introduce main topic of the day- circuits, discuss comical elements in circuit- look for familiar symbols in the cartoon, actual circuit diagram for a transistor radio | "Putting together simple components you can build some cool stuff" |
| 9:40 | "Let's talk about simple circuits- how do you solve problems with this? By the end of this class, you'll have all the tools you need to solve any circuit" | |
| 9:42:30 | Sign conventions | Analogy- "The way to understand this more intuitively is think about it as a river following instead of current following" |
| 9:45 | Quick introduction to the concept of internal resistance | |
| 9:46 | Review series and parallel which "you have probably seen in high school then move on to more complicated stuff", derive equivalent resistance expression for both of these | |
| 9:55 | **Concept question-** bulbs and batteries- what happens to the brightness when a second bulb is added to the circuit? | Student responses were all over the map, instructor talks about it with an analogy of charges trying to leave out of one door compared to two (which would have more resistance) |

| | | |
|---|---|---|
| | | "If a problem looks very complicated, make it general then go more specific" |
| 10:00 | Similar **concept question** but asking about the change in the power output | |
| 10:06:30 | Third **concept question** asking about power output when bulbs are in series | 75% answer incorrectly- asks class what's the trick? Instructor discusses it a little bit then revote, 55% now have correct number |
| 10:11 | Break | |
| 10:17 | "Now we want to do more advanced problem solving"- Kirchoff's laws- take a physics problem, turn it into a math problem then solve it | |
| 10:20 | Demonstration: florescent tube, switch, measure voltage changes across various circuit elements "what does this mean about the magnitude of the resistance" here | Hard for students to see the readings on the voltmeter |
| 10:29 | Worked example circuit: "details don't matter- what matters is the approach" | Instructor made a mistake when he said "resistors are in parallel" and no one spoke up. |
| 10:39 | Group problem on whiteboards | |
| 10:49 | Second group problem: Wheatstone bridge- dismisses class once they finish the problem (no wrap-up or solution) | |

<u>Student-centered:</u>

| | |
|---|---|
| 2 | Instructor explicitly encourages active participation and engagement of students (calls on random tables, says you can pass the microphone to people at the table) |
| 1 | Instructor adjusts lessons based on student questions and comments |
| 2 | Students and instructors use elements of the room to promote interaction (microphone, whiteboard, projects whiteboard work) |
| 3 | Instructor builds on student's prior knowledge and/or elicits/addresses their preconceptions (starts the class with a review and continues to reference past knowledge) |
| 0 | Instructor values diverse perspectives and approaches |
| 2 | Instructor provides frequent feedback to students |
| 1 | Respectful atmosphere where students feel comfortable contributing (only 2 |
| 2 | Classroom discourse focuses on students' ideas (with conceptual, open-ended questions) |

Problem-solving:

| | |
|---|---|
| 0 | Students solve problems that are ill-defined and/or contain excess information |
| 2 | Instructor generalizes/presents/models how problem solving skills/approaches can be applied to other problems (many times he generalizes the procedure and separates the physics from the math) |
| 2 | The teacher acted as a resource person, working to support and enhance student investigations *(during clicker questions, he sometimes adds more information and has them revote)* |

Broad content:

| | |
|---|---|
| 2 | Instructor incorporates interdisciplinary, real world course connections and/or connects to student interests (transformer, transformer radio circuit) |
| 1 | Students provide detailed, qualitative answers to conceptual questions *(instructor often polls students but responses usually aren't very detailed)* |
| 0 | Students engage in metacognitive reflection (thinking about their thinking) |
| 1 | Students develop argumentation skills for situations posed to the whole class (debate, argue, defend ideas, reason logically, question assumptions) |

Collaborative learning:

| | |
|---|---|
| 1 | Students collaborate with nearby students or within groups *(not much during clickers but work together during the in-class exercise)* |
| 0 | Groups collaborate with other groups at the table or elsewhere |
| 0 | Students evaluate each other's work |
| 1 | Instructor circulates around the room and (voluntarily) talks to individual students or small groups of students *(he does address questions of students who raise their hands in class)* |
| 0 | Student work/explanations are shared and discussed *(student solutions never presented)* |

Activities:

| | |
|---|---|
| 1 | Students develop models and develop explanations for novel phenomena *(students did have to compare the resistances of various elements in the demo)* |
| 0 | Students made predictions, estimations and/or hypotheses and devised means for testing them |
| 0 | Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures |
| 1 | Students were involved in the communication of their ideas to others using a variety of means and media *(math when they were doing a whiteboard problem)* |
| 0 | Students used a variety of means to represent phenomena (drawings, manipulatives, symbols, etc.) |

**Appendix B: Chapter 3 Description of Work**

As noticed by the list of authors, this paper was not entirely an independent production. However, I conducted the vast majority of planning, execution and interpretation of the study. I constructed, administered and analyzed survey results. I also constructed the plots and drafted the paper. The grant team members did provide advice and guidance along the way but did not actively construct anything you see contained in this work.

## Appendix B: Chapter 3 IRB Approval

University of Colorado Boulder

Institutional Review Board
563 UCB
Boulder, CO 80309
Phone: 303.735.3702
Fax: 303.735.5185
FWA: 00003492

20-Feb-2014

### Exempt Certification

Dancy, Melissa
**Protocol #:** 12-0470
**Title:** Sustainable Diffusion of Research-Based Instructional Strategies:
A Rich Case Study of SCALE-UP

Dear Melissa Dancy,

The Institutional Review Board (IRB) has reviewed this protocol and determined it to be of exempt status in accordance with Federal Regulations 45 CFR 46.101(b). Principal Investigators are responsible for informing the IRB of any changes or unexpected events regarding the project that could impact the exemption status. Upon completion of the study, you must submit a Final Review via eRA. It is your responsibility to notify the IRB **prior** to implementing any changes.

**Certification Date:** 20-Feb-2014
**Exempt Category:** 2

Click here to find the IRB reviewed documents for this protocol: Study Documents
**Note:**
The IRB recommends that any future non-exempt research that is conducted in this effort be submitted as a new, separate protocol, allowing for a clean submission and more streamlined review process.

**While additional inter-IRB agreements are not strictly required for this study due to its Exempt status, all investigators not directly affiliated with CU-Boulder are STRONGLY encouraged to contact the IRBs at their home institutions to ensure there are no local requirements for their engagement in human research activities.

The IRB has reviewed this protocol in accordance with federal regulations, university policies and ethical standards for the protection of human subjects. In accordance with federal regulation at 45 CFR 46.112, research that has been approved by the IRB may be subject to further appropriate review and approval or disapproval by officials of the institution. The investigator is responsible for knowing and complying with all applicable research regulations and policies including, but not limited to, Environmental Health and Safety, Scientific Advisory and Review Committee, Clinical and Translational Research Center, and Wardenburg Health Center and Pharmacy policies.

Please contact the IRB office at 303-735-3702 if you have any questions about this letter or about IRB procedures.

Douglas Grafel
IRB Admin Review Coordinator
Institutional Review Board

**Appendix B: Chapter 3 Survey**

**Demographic Information**

1) Please confirm the primary institution of employment.
2) Which of the following best describes your institution?
   - Public high school
   - Private high school
   - 2-year college
   - 4-year college/university (Bachelor's degree in your discipline)
   - 4-year college/university (graduate degree in your discipline)
   - 4-year college/university (without a degree in your discipline) Other (please specify)
3) Does your school serve a substantial minority or non-traditional population?
4) What subject(s) do you teach?

**SCALE-UP style instruction at your institution**

SCALE-UP style instruction is characterized by the promotion of social interactions among students and instructors, use of engaging activities during class along with a substantial reduction in lecturing, and a focus on developing conceptual understanding and thinking skills. By having students attempt difficult tasks in a supportive environment, they experience the application of their new knowledge. Students have opportunities to practice teamsmanship, presentation of their own work, and evaluation of the work of others. Classroom furnishings are specifically chosen and/or arranged to facilitate this type of collaborative, interactive, guided inquiry.

5) Which best describes your status with regards to SCALE-UP style instruction?
   - I have never heard of SCALE-UP style instruction
   - I use SCALE-UP style instruction
   - I have used SCALE-UP style instruction in the past but not now
   - I use a modified version of SCALE-UP style instruction
   - My teaching has been influenced by SCALE-UP but I don't consider myself a user I am considering using SCALE-UP style instruction
   - I do not use and I do not plan to use SCALE-UP style instruction
6) If you used SCALE-UP style instruction in the past, what is your current status?
   - I plan to use SCALE-UP style instruction again in the near future if I teach a course that can be done in that format
   - I want to use SCALE-UP style instruction again (if I teach a course that can be done in that format) but I'm not sure if/when I'll be able to
   - I do not plan to use SCALE-UP style instruction again
7) In your use of SCALE-UP style instruction, is there an integration of lab and rest of the class?
   - Yes
   - For some of the courses in which I use SCALE-UP style instruction
   - Sometimes during the course in which I use SCALE-UP style instruction
   - No
   - Not applicable

8) In your use of SCALE-UP style instruction, please indicate the percentage of a typical class session spent with the following instructional activities: (These percentages do not need to add up to 100%). Select from: Never, 1-25%, 25-50%, 50-75%, 75-100%

- Instructor lectures (presents information to class)
- Students solve problems in groups
- Individuals or student groups present solutions to the class

9) In your use of SCALE-UP style instruction, if students work in groups, which of the following is true? (Check all that apply)

- Students don't spend a significant amount of time working in groups
- Students work in groups of 3-4
- Students self-select their groups
- Student groups are randomly selected
- Student groups are assigned to be heterogeneous in terms of ability (based on GPA, score on an assessment, etc.)
- Student groups are assigned to be homogeneous in terms of ability (based on GPA, score on an assessment, etc.)
- Student groups are assigned so female and/or minority students are not alone in a group Students are trained in group roles
- There is an attempt to enforce group roles regularly
- Other (please list)

10) In your use of SCALE-UP style instruction, approximately how often do the following activities occur. Chose from: Multiple times per class, once per class period, once a week, once a month, once a semester, never

- Student groups present their own work to others in the class
- Students evaluate the quality of each other's solutions and/or problem solving
- Student groups are reassigned
- Students fill out contracts regarding anticipated responsibilities of each member
- Students evaluate how they work in a team
- Students use a strategic problem solving protocol
- Students solve ill-defined, complex problems that require approximations, estimations, etc.
- Students are informally assessed with quick conceptual questions (MC, etc.)
- Students demonstrate conceptual understanding with questions/problems that require more extensive responses
- Students engage in short lab activities (simple measurements and/or observations)
- Students use computer simulations/animations/applets (ie PhETs) to visualize abstract phenomena
- Students use computer programming to dynamically model processes

11) The classroom where I use/ used SCALE-UP style instruction is designed to enhance group interaction in the following ways: (check all that apply)

- Round tables
- Special, but not round, tables

- Laptops/computers for each individual/group Handheld whiteboards for each group Whiteboards on the walls
- Video/document cameras to display student work Classroom response system (ie clickers)
- Other (please specify)

11) Who is the best person at your institution to contact if we want more information about SCALE-UP style in your discipline at your school?

12) How long has SCALE-UP style instruction been used in your discipline at your institution?

- Less than a year
- 1-3 years
- 4-6 years
- More than 6 years
- Don't know

12) To the best of your knowledge, approximately what percentage of instructors in your discipline are using SCALE-UP style instruction to teach introductory courses at your institution?

- 0-30%
- 30-60%
- 60-90%
- 90-100%
- Don't know

14) Which of the following best captures the attitude of faculty in your discipline regarding constructing SCALE-UP style classroom? (check all that apply)

- We have a classroom specifically designed to facilitate SCALE-UP style instruction
- Faculty never really discussed constructing these classrooms
- Faculty considered construction but it would be difficult to find people to teach in these classroomss Faculty considered construction but the financial investment is problematic right now
- There were classrooms built in the past but they are not currently used for SCALE-UP style instruction
- Don't know
- Other (please specify)

**SCALE-UP Use at Your Institution**

We want to get an idea of which subjects are being taught in the SCALE-UP style format and see where this style instruction has spread. At your institution, what other subjects are currently being taught using SCALE-UP style instruction? (Select all that apply and list SCALE-UP style instructor/ contact person, if known). In order to get a complete picture of SCALE-UP use nationally, we may contact some of the people you identify with a survey similar to this one.

15) How did you learn about SCALE-UP style instruction? Please add details if you can recall them-- they will help us understand your response in more detail. (List one per category: First heard about SCALE-UP, Learned the most about SCALE-UP)

- Formal talk/workshop (where and by whom)
- Website (describe):
- Reading (list book or article):
- My department was using it when I arrived
- Another department at my institution was using it when I arrived
- My department was using it when I was in graduate school
- Colleague in my department (name):
- Colleague in my institution but not my department (name):
- Colleague in my field but not my institution (name, institution):
- Other person (explain):
- Other (please specify):
- Don't know

16) Instructional ideas like SCALE-UP often spread by word of mouth. Have you helped influence anyone, even in a minor way, to implement SCALE-UP style instruction? Please briefly describe the interaction and any impact you are aware of.

- People in your department (name):
- People in your discipline at other institutions (Name, organization):
- People at other institutions (Name, organization, discipline)

**Appendix C: Chapter 4 IRB Application**

Project Description: *Describe your project by providing a summary and answering the requested information below.*

1. Project Summary. Please make sure to include the purpose and rationale for your study and overview of your methods.

When innovative teaching strategies and educational reforms are implemented, users often modify and adapt the reform to fit the local setting, student population, instructor personality and the current situation. Research on the diffusion of innovations says giving users the flexibility to modify reform improves user satisfaction and the probability of sustained use. However, some instructors the reform in ways that may compromise the effectiveness of the reform. This study will examine h SCALE-UP reform has adapted and evolved through curricular changes at NCSU. Studying how a successful reform adapts to changing curricula will identify elements of the SCALE-UP reform that potentially should remain constant and others where users have more flexibility to modify at their o This study will examine longitudinal course documents (syllabi, daily agendas, instructors notes, assessment) before SCALE-UP implementation with a traditional curriculum, Matter and Interaction curriculum and the reversion back to a more traditional curriculum. Key aspects of the reform and coverage will be monitored during these time periods to see how they changed during implementation why. The developer of the reform and instructor will be interviewed about his course goals/objectives his perspective on what changes he made and why. After completing this extensive review of the adaptation of curricula and reform at NCSU (the development site), interviews with key implementer three other sites (probably George Washington University, Ithaca College and Massachusetts Institute of Technology) to see if initial patterns carry over to these other places.

1. Describe your participant population. This includes age range, inclusion/exclusion criteria, an vulnerable populations that will be targeted for enrollment.

The only humans involved with this study will be key implementers/instructors that use the SCALE- reform- one at NCSU and potentially a few more at each of the three institutions listed above.

2. Describe how potential participants will be approached about the research and how informed consent will be obtained. Alternatively, provide an explanation of how informed consent will obtained. Include a copy of recruitment materials, such as, scripts, letters of introduction, emails with your submission.

The PI will e-mail potential participants (faculty members and administrators involved in implementing or teaching using SCALE-UP style instruction) introducing themselves, the project and objective of the interview. Before they are interviewed, they will read and sign the consent form. I will offer faculty the opportunity to be indentified in publications (which is completely voluntary). After they complete the interview, they will be given the opportunity to opt out of the study. Otherwise the audi of the interview will be retained until it is transcribed. Recruitment materials are attached.

3. Describe how identifying information will be recorded and associated with data (e.g. code num used that are linked via a master list to subjects' names). Alternatively, provide details on how data will be collected and stored anonymously ("anonymously" means that there is no link whatsoever between participant identities and data). Describe management of data: security, storage, access, and final disposition.

1) Interview of faculty members will be audio recorded and transcribed . Any identifiers created during data analysis and used in reporting will be randomly assigned to distinguish one interviewee f another . These serve a research purpose there are no risks to compromising subject anonymity . Individual responses from the faculty interviews will be described.
2) The course documents don't have any personal information .
All audio data will exist in electronic form, stored on a secure PERD group server with access restricted to members of the PERD group. As the amount of data accumulates on the server, data transferred to external hard drives secured in the PERD observation room by lock and key. Additionally, the drive itself will be password encrypted to secure the data against loss and theft. PERD group members are allowed to use the data and its analysis in future research projects. All data may be keep indefinitely.

4. Provide a detailed (step-by-step) description of all study procedures, including descriptions of the participants will experience. Include topics, materials, procedures, for use of assessments (interviews, surveys, questionnaires, testing methods, observations, etc.).

Recruitment of faculty members and administrations will be entirely voluntary. Faculty user SCALE-UP style instruction who were key implementers with SCALE-UP . Requests of faculty participation will be sent out via e-mail and the PI will be available via e-mail, telephone or Skype to review the study, answer any questions and/ or address any concerns. Faculty will then have the o opt-out of the study or participate and grant their consent on audio at the start of the interview. To included in the study , these faculty members will need to be key implementers or instructors of SCA at their institution .
Interviews with faculty members will either take place in person or on the telephone/Skype . PI will audio record the faculty members giving their consent then audiorecord the interview. The s are also informed that in order to help maintain their anonymity and those of specific people mentio during interviews , these names will be assigned pseudonyms during transcription and audio records be deleted after they are transcribed . Data will be stored on a

secure server in a room under lock a key. The interview of the faculty members will take approximately 1 hour.

5. Will minors (participants under the age of 18) be recruited for this study : No

6. Is this study funded? Yes
a. Is this study receiving federal funding? Yes
b. If yes, please provide the grant proposal or any other supporting documents.

7. Do you have a conflict of interest or significant financial interest in this research? No

Sample solicitation e-mail: Dear (professor),
My name is Kathleen Foote and I'm a physics PhD student at North Carolina St University, working with Dr. Beichner. I visiting your university in (****) to observe so of your SCALE-UP-style classrooms and talk to instructors about the implementation of t reform. I'm currently working on the final chapter of my dissertation, "Mutual adaptation curriculum and instructional reform: The case of SCALE-UP in university physics" a hoping to speak to some key implementersjfaculty more specifically about the curricular aspect of the reform.

I would like to interview you about the history of the SCALE-UP reform and curriculum because your perspective is very important to us. The telephone interview will l approximately 60 minutes and be conducted at a mutually agreeable time. Questions focus on your personal experience with SCALE-UP and the physics curriculum, in the p and today. It will be audio recorded for the use of the research team online. Participation entirely voluntary. If you do not wish to participate, please let me know so I don't both you with further requests.

If you can help me by participating in a telephone interview, please reply to this e-mail with three times that would be convenient for you . I will try to accommodate your first choices
Sincerely, Kathleen Foote
PhD Candidate
Physics Education Research Group North Carolina State University

**Sample Interview Questions for SCALE-UP instructors and key implementers:**
**Overview /background:**

1) Tell me about the history of the SCALE-UP(style) reform at your institution?
2) What are your course goals/objectives?
a. How have these evolved?
b. How do you assess whether you are meeting these goals?
c. Which are the most challenging to meet?
3) What curriculum did youjdo you use during this time? Why?
4) Who designs the curricula at your university? How much freedom do instructors have to modify it?

**Details of curricula:**

5) What textbook/course resources do your students use? How much do you think your students use them? Did using the textbook help/harm the attempted implementation of SCALE-UP?
6) How do you assess your students? Who develops the assessment? What format did you use? How does it align with your course goals/objectives? What content is typically covered? Do your assessments target any higher order skills?
7) What does a typical day look like? Who develops class assignments? (homework, in class, labs) How have these evolved over time? How similar is your class to other sections at the university?
8) How was your content coverage affected by the implementation of the SCALE-UP reform? If you had to cut topics, which ones did you chose and why?

Details of SCALE-UP reform

9) When you decided to implement SCALE-UP, how did you redesign your classroom
10)What elements of this reformed classroom did you use on a daily/weekly/monthly basis?
a. Which elements of the most helpful? Which elements of the room didn't work so well?
b. How did the room design change over the course of the implementation?
11) How do you structure collaborative learning in your class? How has this changed?
a. With what kind of activities/content does collaborative learning work well What activities do you think work better with students working independently or an instructor-led activity?
12) How do you plan activities? Do you purposefully plan tangibles, ponderibles and visibles?
13) How do you address conceptual learning and problem solving with your course? Higher order cognitive skills?

## Appendix C: IRB Approval

North Carolina State University is a land-grant university and a constituent institution of the University of North Carolina

**Office of Research and Innovation**
Division of Research Administration

**NC STATE UNIVERSITY**

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From: Jennifer Ofstein, IRB Coordinator
North Carolina State University
Institutional Review Board

Date: April 25, 2014

Title: Mutual adaptation of curriculum and instructional reform: The case of SCALE-UP in university physics

IRB#: 3959

Dear Kathleen Foote,

The research proposal named above has received administrative review and has been approved as exempt from the policy as outlined in the Code of Federal Regulations (Exemption: 46.101. b.2). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review. This approval does not expire, but any changes must be approved by the IRB prior to implementation.

NOTE:

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations. For NCSU projects, the Assurance Number is: FWA00003429.

2. Any changes to the research must be submitted and approved by the IRB prior to implementation.

3. If any unanticipated problems occur, they must be reported to the IRB office within 5 business days.

Please forward a copy of this letter to your faculty sponsor, if applicable.
Thank you.

Sincerely,

Jennifer Ofstein

Jennifer Ofstein
NC State IRB

**Appendix C: Chapter 4 sample interview and analysis**

To protect the anonymity of respondents for my Chapter 4 study, I will present a sample interview and analysis that was not part of my data set but I used as a pilot to practice my procedure and refine my interview questions and procedure.

KF: Can you tell me about key changes during the SCALE-UP reform at your institution.

B: We started with testing it in a lecture hall and we had the paddle desks replaced with lab tables and that was in 1995-1996 and JR taught in there. It was a total disaster. Students complained about the activities, saying they were childish, and they couldn't get out of their seats to get equipment, we couldn't get equipment to them, the tables were just small enough that it couldn't fit laptops- they kept dropping their calculators and they couldn't get out to whiteboards. It was a disaster. At that point, John said in 20 years of teaching, it was the worst experience he ever had.

So I decided to redesign the classroom so we had 209 Cox which had 9 students at a table, they were 6 feet round tables, 6 of them so we had 54 students. We borrowed tables from a hotel for awhile because 6' is the standard diameter. I think we were in that room for 3 years, 1997-2000. Eventually, we gave the tables back and bought our own tables but they were still 6' in diameter and it was really tight. It was something like 22x36"- it was really tight. We brought in laptops on carts- they were Hewett Packard laptops, one per team of three. The students had to take them off the cart, plug them in, hook them into the network manually because it was a wired connection back then. And we did that twice a day for three years. The only hardware problem we had is we broke one pin on one plug and a student broke a screen on one laptop. They had a magnet in their hand, got excited, it flipped out of their hand and hit the screen. Hewlett Packard actually came to visit us- they gave us a grant- well, I requested 20 laptops for the room. They said, we can't give you laptops but we can give you desktops for the room. They didn't say this but their profit margin was big enough on the desktops that with the tax break, they would come out ahead. With laptops, there's a very small margin so even for donations, it would cost them money so they didn't want to do it. I said "thanks but no thanks" and evidently had no one turn them down for a classroom of computers before so they gave us the laptops. They came to visit a year later to see if we really needed them. And we did. And they admitted we did. So we did that for about three years then the new classroom was being built in Harrelson. It took us a long time to find space. We considered space under the ballroom in a hotel that the university bought over on Avent Ferry. It is now a dorm and it had a ballroom and they were considering using that as a classroom space which would have been really inconvenient but it didn't work out because they were storing communication cables underneath the hotel in the ballroom and there's another fire code. So we couldn't do that. We looked at inflatable buildings, pre-fab buildings, domes on top of Cox Hall but because it was for such a big room, you couldn't just put up a building. You needed a restroom which meant you needed plumbing and drains so we finally found the space under Harrelson. In those days, the central core was there but everything else was on pillars so you could just stand there and look across and see there was nothing except for the center. So they figured, all they had to do was put up exterior walls and you have a room. It took them awhile to build it and you know there's lots of problems

with it- low ceilings, it's curved, lots of ways they didn't follow my requests. But it was constructed and it actually became available in the middle of the semester. I think it was in the year 2000. So we moved the 54 students over and used half that room, which was probably a good idea to get some of the bugs out. And then, from then on, we've had our big room over there of 99 students. Not so many years ago, maybe three years ago, there's a smaller classroom for 45 which opened up besides it. There's sort of SCALE-UPy rooms in geographic information systems in Jordan Hall, there's stuff, kind of a flexible studio space in the English department for first year writing, biology is now doing SCALE-UP and they'll keep doing it as much as they can get the room. Chemistry has been doing it for awhile. When Fox hall was being designed, there was going to be a SCALE-UP classroom and the architects were very excited about it. It was going to be a major part of the first floor with glass walls and the way around it with students writing on glass but then it kind of just went away. I don't know who killed it but someone killed it. The rooms upstairs were supposed to be used by chemistry and so even though they weren't designed as SCALE-UP rooms, they were used that way and eventually, once people realized 'they are going to do this anyway', they took out some walls and now it is a better SCALE-UP space but it is still not round tables or anything. Where we are now, Harrelson is going to be coming down in a year or so and it looks like the dean's office suite, which is the first floor of Cox hall is going to be where those SCALE-UP rooms are moved to and that frees up Harrelson for it to be ripped down. The noises that I'm hearing are that the new building will have multiple SCALE-UP classrooms. It seems to have growing interest here on campus.
KF: (6:51) What were your goals and objectives of implementing SCALE-UP in the first place?
B: I had been team teaching an integrated course- math, engineering, chemistry, physics, the faculty sat in on each other's classes, developed joint activities and assessment. They were in the same room for all of those courses and they could use that space after hours so it became a game that the last team would write the time that they left. So you'd come in in the morning and see that team 3A was here until 2 AM and stuff because they could use the space however they wanted. So that's where I could experiment with table sizes and stuff because we could do whatever we wanted there, with different tables and arrangements and geometries. I read students journals, took field notes in there as well as in the classroom. Excellent educational experience for the students but it was way too much work for the faculty so we broke that apart and I wanted to use all the research-based pedagogies that we had been using with 36 back in my regular class which had to have 100, which I was told. It had to have 100 students, 1 faculty member and one teaching assistant and cover the same content. So that's where SCALE-UP came from- how do you scale-up the pedagogies that were designed for a much different student to faculty ratio. I mean the tutorials were designed for 24 students, 3 or 4 instructors but we couldn't do that. So that's how it came about so the question was, how did the work that I did in the IMPACT classroom with round tables but I tried using the standard size with 9 students but it was too small so that's when we went to Cox.
KF: Too small for the equipment?

B: Too small for the equipment and the students were just too packed together. That's when we decided to go to the 7' tables (9:09) and we had a bigger classroom because I won't be able to keep teaching 24 students. In order to get the classroom, I had to make deals. One of the deals was that to get the classroom, it had to be a computer lab which meant that there had to be a computer for every student instead of for every three which was a substantial change in how the class operated. And it gave us opportunities to do things that we hadn't before, like quizzing but it is challenging when every student has that huge distraction in front of them.
KF: How does that translate into course goals and objectives?
B: Originally we had much more interdisciplinary course goals because it as integrated across different courses. Once we split that apart, that integrated aspect went into the introductory engineering course where it still is. That meant modifying, coming up with new activities that were just physics. Ponderibles and tangibles and such. We didn't have visibles back then. When we were in Cox, just doing physics now, is when I was working with John Risley and Jeff Saul and we came up with 'these are the course goals to the two-semester sequence" and understanding the physics, technology and communication skills so those have been constant throughout. When you get to the finer grain size, performance outcomes. I never had those written up until M&I and when Ruth and Bruce came here and I adopted Matter and Interactions, that was a substantial change in how the course operated. I had co-authored that book.
KF: Before you go there, was there a reason the performance outcomes had to be written out with M&I?
B: No, I just realized that it had to be done and it took awhile to get everyone else along for the ride.
I co-authored that book with Serway and tangibles- well, I don't know if you've looked at the book but there's quick labs and quick quizzes in the margins and those were ponderibles and tangibles. So I co-authored that book, it was selling really well and we were zooming along but then I was not invited back because I made all the changes they wanted me too and more. Anyway, so I signed a contract with another publisher who wanted me to write my own book. I had written three chapters then I saw the M&I book and realized I couldn't write anything that good so I stopped that project, got out of the contract then Ruth and Bruce came.
KF: So they weren't here when they wrote M&I?
B: They were at Carnegie Melon when they wrote the first edition but it wasn't being adopted by anyone because it was a substantially higher level than it is now and it is pretty high level and it is pretty high level. They saw it as coming to NC State would allow them to have more normal students, because Carnegie Melon students are pretty high level students. So we found a way to get them here, which was a project in itself but they were interested in SCALE-UP but it never really fit the way that they teach. Ruth tried it but she isn't that free. She likes it much more directed. So I used it which meant a whole other batch of activities and such. When you look at the books, you can see I kept some and added some. One thing that changed is I started using their tests, until then I had been writing my own tests, other than when I was matching tests to assess the whole thing and so that kept me a little more

rigid than I was used to, but in the end, I think it was a good thing. But now that they've left and especially since I'm more separated from the rest of the department, I'm writing my own tests and things. I actually prefer that, greatly. But the overall goals have been the same. Getting physics content across better than before and giving students exposure to 21st century skills like communication and problem solving (14:18) and critical thinking and all that stuff. Teamsmanship.
KF: It sounded like the whole time you were free to chose the curriculum that you liked? And only portions of the time you had to have the same assessment as the rest of the department?
B: I didn't have to, I just did. That was one of the things that the department has been good at- letting me do whatever I want. They may or may not support it in other ways, like providing graders and such, but they do allow me freedom.
KF: When you could write your own tests, what would be different about your tests compared to theirs?
B: They would usually be harder, more open-ended. When I had more assistants, because there would be times when I had a graduate student and an undergraduate or even a couple graduate students, I gave substantially more open-ended questions because I could. When I was in the class of 54, I don't think there were any multiple choice questions at all. They were all very open-ended. Like you work for a toy company and their task is to design a spring-loaded suction cup dart gun and the legal department is concerned about it. That was the problem. I remember another one was you're playing with a yo-yo (15:58) and you wonder how fast it spins. I remember that one because there must have been multiple SCALE-UP sessions so I didn't know everybody so we had everyone in one big room somewhere on campus and a student from another section came in by mistake and sat there for 45 minutes out of an hour and half and hadn't written anything done. Finally, he raised his hand, pointed to the yo-yo question and asked "are we really supposed to know how to do this?" and I asked "are you a SCALE-UP student" and he said "noooo". It's interesting because it points to one of the difficulties of doing research. One of the things I did was give exams written by lecturers to my students to prove they did a letter grade better. You can't do that in reverse because it isn't fair to the lecture students so there's fundamental limitations to what you can get away with. (17:20)
KF: How did the content coverage stay this whole time? You said you were expected to cover the same content. Did you have to make cuts? And if you did, what did you cut?
B: We covered the same amount of content, usually in more depth. The only way you can do that is expect more responsibility outside of class.
KF: How have your student used the textbook and course resources over time? How has that changed?
B: Well I've varied that. I've created videos for them and I'd like to do more of that because they seem to like that. They come to class well prepared since they are assigned certain sections of the textbook and there's homework due on them before they come to class. There's been times that I've asked them to find more materials and bring them to class. I've toyed with the idea of having the class generate a wiki book each time but that seems like it would be a lot of work and I'm not sure how that would function so I'm still toying with that

one but we're covered all the content as before and I've never had students come to class unprepared.

KF: Besides tests, how has the assessment of students changed?

B: Early on, I had much more research assessment. I had field observers, I observed video tapes of class. That's really fun actually because you can watch the instructor ping between tables and it looks like ping pong. You can track patterns, like I'm not getting to the outer edges or I'm not seeing that table, or that table is dominating the questioning. With different table sizes, we had a lot of assessment of those with discussion across tables. It is pretty hard to do that, we had big monitors because that was back before laptops and all those. We had the TUG-K until it got to the point where they were doing so well, the post-test scores were averaging above 90% so I just stopped doing it. It may be interesting to try that with M&I because we don't have nearly the emphasis on kinematics as we did before. But anyway, so I did the TUG-K, FCI, MPEX for attitudes- this was before CLASS, the BEMA and I don't think we didn't any other E&M. Well maybe the CSEM a couple times. It got to be, well I had to cut back and finally I don't do it at all because it gets in the way of the class. And I haven't needed to do that aspect of things. I've taken questions from the lecturing classes and given those to the SCALE-UP students. I checked for volunteer basis by taking people who signed up for SCALE-UP and sent them back to the lecture sections to track them to make sure that there weren't some special group of students in SCALE-UP to see if there were some special group of students that wanted to learn more than others.

KF: What about formative assessment?

B: That's really the quizzes and that came about because the students asked for them essentially. They would complain that they aren't doing very well on exams even though they were doing very well in the class and on homework (21:33). Eventually I figured it out that it was because the only time they were individually responsible was on tests so they didn't recognize what they didn't know. So now we have quizzes every week. How early on did you add those?

B: Probably 10 years ago. But I didn't want Fridays to be hated days "oh man! I have that quiz" so that's when I came up with the idea where they take the test individually at first, so they are individually responsible but then they can get 70% with the group. So they're not going to get less than 70-75% and they'll leave knowing how to do the problems. So that worked out pretty well. Students were happier about that and I think it worked out well.

KF: How do you add clickers and when did you add those?

B: Well I was using clickers before we had clickers. I was asking questions on WebAssign but it turns out, that's a hassle because you have to keep making assignments and it isn't easy to add a question on the fly and it is not easy to have the students answer a question over again. So once the clickers, the physical devices came out, I switched to using those… it's probably been 5 years.

KF: After Peer Instruction?

B: Yes , I certainly didn't invent those. That was Eric Mazur. Another thing that did change was the use of WebAssign for the activities (23:42). Originally I just had webpages for every day, every class day- you know, here's an activity, do it. Here's an activity, do it. That worked fine but John Risley, you know, ran Webassign, put all of that stuff on Webassign

and what he found is students work harder if they have to put something in a box. You know if they get a green check, there are willing to work for it. So I do all my activities, well three-quarters of them, Webassign-based.
KF: Webassign was used from the beginning?
B: No, webassign didn't exist from the beginning. No I just put up a webpage for the course and a webpage for the day, with a list of activities, which is good because the students could see what they are expected to do.
KF: So they could see what they were expected to do, but they didn't have to input anything.
B: Right, they just did it on whiteboards.
KF: Were there any specific physics units or topics that were really hard to cover with this approach?
B: Ya thermal physics was hard. If you're doing calorimetry, it is hard to get water in and out of there, some of the problems which chemistry has. Charge to mass ratio is hard because those tubes are so big and bulky and expensive- we only have one of those so it's like "Students, here's the apparatus we have. You tell me what measurements to take", that's all we can do. I think we did that, didn't we? And the other one that's difficult is young's modulus because there's only one piece of equipment per table so it is mostly equipment and lab based issues. Originally, I was using three frictionless tracks, which worked ok for 54 students but with 100 students, there was just too much interference with the Sonic Rangers and I think it worked out a lot better to have three activities running simultaneously which appear to be different on the surface but are all connected.
KF: Is there certain activities or content when the collaborative approach works better than others? Or certain topics that students were inclined to individually or certain topics you felt like you needed to cover in more detail than others?
B: I don't think there's any topics that particularly benefitted from a group approach except occasionally, I would do jigsaws where people have to share information. I should do more of that, since it does appear to work nicely. I can't think of any topic where collaboration would have made it a difficulty or not. I found that I talk too much. I found that I talked too much when I used a tablet with Microsoft OneNote and write things on that and post the PDFs after class. The students really liked that, having the PDFs posted but I realized that I was talking a lot more and I don't think any student was in a situation with they had one semester with and one semester without.
KF: Did the amount that students worked on whiteboards? The amount that students used the lab equipment change over the course of your time?
B: When we were in the smaller classroom, we had to wheel the equipment in and I had them do more whiteboard there because it was possible to for every group to get to a whiteboard because there were just fewer groups. In G108, it's hard to get each group to a whiteboard. You can do each table but it's hard to get each group since I have lot less space available than we did. If we had a better shaped room, I think we could. Another thing that changed once we got over that, is the lab equipment was present in the classroom. When I switched to M&I, which had a much more rigid curriculum, I stopped doing it but when I was teaching traditional content in G108, many of the labs were much more open-ended. I'd say there's equipment over there, that's a really good question, go answer it. SCALE-UP was much

more open-ended, and probably closer to what I imagined as the ideal curriculum before I switched to the M&I curriculum, which is much more rigid.
KF: Are there challenges associated with using M&I?
B: It's more abstract. It's much harder to come up with tangibles and much more of the content is dealing with sub-atomic particles. In the traditional curriculum, I did much more with how things work- radio station and car antennae. You have the frequency so you can find the wavelength and the antennae is a quarter of that so that kind of thing, mixing in conceptual and practical applications. So that lends itself more to tangibles than M&I stuff. But I like M&I, I think there's a lot more physics in it. If I was teaching physics majors, that's for sure all I would use. With engineering majors, you have to work to get additional practical things in there but you can. It would be helpful to modify it to have a version for physics majors and for engineering majors, it would require some substantial changes probably.
KF: And you're still using M&I, even though the department switched back?
B: Yup
KF: Those labs that you said was more structured. You kept them more structured? You used them as is?
B: For example, with the lab when you stretch the wire and we only have equipment one per table, there's not much open-ended that you can do with that. I tend to be a lot more vague in what I would have students do than these labs are. These labs always have handouts on the web with pretty explicit, do this, do this and the labs before, were much more open-ended. There was rarely any open-ended questions at all and teams would be using completely different equipment which was fun because you could start arguments about which one was better. (33:27) I remember one for oscillations with springs and masses that I told them that they could make any static measurements they needed but I wanted a graph of oscillations over time and so different people would do different things. The smartest groups would hang the spring on the whiteboard and just mark where the spring was going. Others would use low-friction tracks on the table, because I didn't tell them what to use which was fun about it, so they'd find k, measure the mass to calculate the period then show me the graph and they'd ask how big the amplitude would be. I'd say "well, you don't want to break the spring but other than that", then I asked "but does it matter?" and they'd think about that and realize that it didn't matter. And I'd say that's good, go verify it and when they went to verify it, they found it didn't work. Some people would go get sonic rangers because maybe they were just bad with the stopwatch. I'd get e-mails from people apologizing because they just got so mad. What they realized, well I had to help them, that the mass of the spring was greater than the mass hanging off of it so you had to account for it. This was before Vpython and so we used a graphics package called Interactive Physics and you could make circles and squares and stuff but those objects behave like physics objects. If you put a circle, it would fall unless you put a floor and then it would bounce, you could add a coefficient of restitution or something. So you could model it, and the model matched their predicted graph but they knew that wasn't right and they finally started to recognize, the team would take the spring and put it on the scale. Other teams would ask, what are you doing that for? So they had to realize how to deal with that and you can analyze it analytically. If it was a class for physics

majors, I would make them do that because it turns that you have to take a third of the mass of the spring and add it to that. But they couldn't do it but they had to account for it with Interactive Physics so they split up the spring into smaller springs with masses in between but then they had to figure out how strong those springs had to be, which couldn't be as strong as the whole spring. Because if the whole spring stretched a centimeter (36:43) well each of them would also for the same weight on the end. So they pretty quickly figured out that if you had ten little springs, each spring had to be ten times as strong so they did that and ran it. Right on the nose. So that's an example of a much more open-ended lab and I probably could come up with something. I used to have them do the jumping lab where they would crouch down and launch themselves, and instead of the detailed calculations, I asked what fraction of a M&M do you burn off in jumping once. I gave each group a small bag of M&Ms so they could look on the back and see this is 150 calories then they counted them out, found out how many calories per M&M and figure it out from there.
KF: You did M&I without Vpython for a bit?
B: No, I think we always had Vpython with M&I. But we've changed how we use M&I. We now give them working problem stems, based on Brandon's work, well really Sean's work, a minimally working program because what he found that if the students had to work on making the program work from the beginning, they weren't interested in making it run well, as long as it ran. So now what we do is we give them a program that runs so they have to fix it and add in the physics because there was no gravity or something like that.
KF: The biggest change when you switched from a traditional curriculum to M&I was what?
B: The lack of flexibility and open-endedness of the curriculum and activities.
KF: Because it was more abstract?
B: No because it was all interconnected because it really is a package and all the pieces need to be there. In a real lab, if they were getting a lot out of the oscillations and stuff, I'd spend more time on that because they were really getting a lot out of it in terms of how science works. In M&I, I couldn't do that because each piece is part of the package and later on, you change something here and it disrupts everything all down the line. For example, you pull on the wire and find the inter-atomic stiffness then you use that to calculate the speed of sound and you measure it and you use that to look at the thermal properties so it'll have ramifications all the way down. I wouldn't be able to do that, with Ruth and Bruce here to scramble all that and now, I've come to realize over time as I talk to people about SCALE-UP, I talk about the flexibility of SCALE-UP and the things you can have students do. I think that's something unique in this approach, and if you're able to, you can customize the course on the fly to fit student needs and interests. In a lecture, that's hard to do because you don't get much feedback from the students… When I tell people about SCALE-UP, I tend to tell people about activities that I used to do when I had more flexibility. Well, I do talk to them some about what you can do with M&I, especially with the visibles. The programming is much better than it used to be than when I had them use the graphic conversion tools to create situations.
KF: When people use different curricula, what are the most important aspects to keep constant?

B: Across curricula, it's not just physics. You need some sort of furniture arrangement that facilitates students working in groups. It is really hard to get this working in lecture halls. People ask if you can and I try to steer them away from that because of the difficulties we had. I also think there are benefits, as we are finding, to having made the leap so that when that person leaves and another person comes, "now what do I do?" and so that I think the redesigned furniture is an important part of it. And the collaborative group work and the aspects of that which makes it work is also important. Heterogeneous, I used to put a star at every table and I should think about doing that again because that works really well. I used to have anyone that was from an underrepresented group so they aren't alone but that doesn't seem to be an issue any more. I used to have the same groups all semester long but that didn't work. The only thing that I'm particular about, I don't care if they call it SCALE-UP or give SCALE-UP credit, even though it is nice when they do. But if they call it SCALE-UP and they are doing groups, they have to be doing the things that I recommend. If they're going to call it SCALE-UP and not say they're doing like SCALE-UP-type stuff, that's the only thing that I insist they keep constant. I say "you can tell people anything you want but if you're saying you're doing SCALE-UP groups and not doing these things, I will protest."
KF: Do you think Webassign has affected the way the groups function?
B: It makes groups easier in the sense that it makes the groups for us so that saves some time. But not really.
KF: The way they input things on the computer?
B: It keeps them more focused, in terms of working in groups. In fact I think they were more likely to work on a whiteboard before because they had nowhere else to put it but with webassign, it doesn't matter if they do it on a whiteboard or on paper to them. It does for me. So probably they're less likely to use the group whiteboards with Webassign but it's worth the benefit of keeping them focused.
KF: Are there any unique benefits or challenges specific to physics in a SCALE-UP environment?
B: I think it has a lot of benefits. There's lots and lots of activities you can do and you can do things inductively or deductively. You can give them something and have them ponder the formula that describes the shadow made by this cardboard piece or give them a lamp and have them explain how it works. So you can go either way. I think physics has advantages over math, for example. With things like mathematica and maple, math is getting closer to being kind of a sandbox where you can give them interesting to explore but it's harder. Chemistry is better but then you have chemicals to worry about. Biology you can do it also but things take time because they are living things. So probably of all the disciplines, physics is probably the easiest to implement this approach.
KF: Interesting. If people ask what textbook or curricula they should use, if the want to do SCALE-UP?
B: SCALE-UP is a classroom environment and a way of teaching in that environment. It influences things. Just as we've seen, it changes, as we've seen when we switched to M&I but when people ask what is the approved physics content, I respond there isn't any.
KF: I think that's it. Thanks!

- Adopt: At the adoption pole, the change agent develops all of the materials and procedures and gives them to the instructor to implement as is. Ex. Use of FCI as assessment instrument.
- Adapt: Under adaptation and reinvention, the general idea of a new instructional strategy comes from an external source, but the instructor is responsible for developing important aspects of the strategy. Ex. Use of Physlets… developers say that Physlets can be used as classroom demonstrations, but leave the instructor to adapt the resource to his or her own pedagogical strategies
- Reinvent: Under adaptation and reinvention, the general idea of a new instructional strategy comes from an external source, but the instructor is responsible for developing important aspects of the strategy. Ex. use of whiteboards
- Invent: At the invention pole, the instructor develops everything with minimal external influence- develop own strategy. In its extreme, this pole represents an instructor view that educational research is irrelevant.

Summary Analysis based on interviews, literature and e-mail correspondence

**SETTING THE SCENE (RQ1):**

**Influences:**

• IMPEC (Institution): Interdisciplinary, collaborative, active learning studio course that Beichner taught for 36 engineering students

o Successes: "Although the IMPEC classes were highly successful in minimizing attrition, improving student understanding of the course material and providing a positive learning experience for 36 students per year, the project was suspended because it was impractical to expand the program to more than a small fraction of the thousands of students entering the NC State Engineering program each year" (B et al 2008, p.4) created a community (studied together outside of class), fun to teach that way (B interview 4.17.14, p. 1)

o Challenges: integrated curricula, took too much time, too many faculty

o REINVENT: Broke course apart, had to come up with tangibles and ponderibles just for physics

• Active Learning (Felder- institution)- general inspiration to do activities during class instead of lecturing (e-mail correspondence 1/16/2015)

• Collaborative Learning (Literature- Johnsons)- REINVENT

o Individual accountability- reading quiz/ homework prior to class, Friday quizzes

o Positive interdependence- shared materials, group grades, teamsmanship bonus, group roles

o Face-to-face interaction.- round tables, whiteboards, shared materials

o Appropriate use of interpersonal skills- group training videos, group contracts,

o Regular self-assessment of group functioning- group contracts, rotate groups, 10% of grade for teamsmanship

• Workshop Physics & Studio Physics (RPI)- INVENT

o Studio physics were for small classes of 30-40 students, different classroom design o Beichner talked to Priscilla Laws about video analysis- she wanted to know how to do it and he wanted to know about the physics of dance (which her husband studied)- conversation wasn't specifically related to SCALE-UP (e-mail correspondence 1/16/2015)

**Goals**

"Scale-up" interactive pedagogies meant for small classes- "effort to create studio classes that would be large enough to provide an effective, yet affordable alternative to the standard lecture/laboratory format at large research universities" (Beichner et al. 2008)

- Synchronize lab and lecture sections
- Teach physics better than before (improve problem solving and conceptual learning)
- Teach real world skills (technology, communication, team work)
- Create "neighborhood" at large university

**Challenges**

- Low-student faculty ratio (1 faculty, 1 TA, 100 students)
  - o Webassign keeps students on task
  - o Students teach each other
  - o TA is usually a PER graduate student familiar with innovative teaching
- Limited time for grading
  - o "Use of student groups cut many of grading by 2/3" (FIPSE)
  - o Webassign
  - o Random homework table checks
  - o Sometimes have students grade each others
- Diverse student population (different academic preparation)
  - o Heterogeneous groups
  - o Star at each table
  - o Teammanship bonus and group contracts
- Same content coverage as other sections
  - o Students read textbook outside of class and take quiz or do homework before coming to class

**Precursor:** Paddleboard desks in lecture hall (1995-1996)

The stage 1 s-up class was done in a lecture hall with more than 100 fixed, stadium style seats. That was such a disaster that after a semester I moved all the paddleboard desks out of a regular classroom (flat floor, not a lecture hall) and installed 54 seats—six round tables (6 feet diameter) with nine students at each. No outside labs. That was stage 2.

**Room**

- 55 students paddleboard seats (moveable)
- Handheld whiteboards
- Lab equipment for "string and sticky tape" activities

**Curriculum:**

- Integrated lab/ lecture
- Tangibles, ponderibles

**Instructional Practices/ use of technology:**

• “An outline of each day’s class is usually presented on a single web page. This brief overview usually fits onto a single computer screen and provides students with an advance organizer28 of the day’s work” (B et al. 2008, p. 11)

**Successes:**

• Integrated lab-lecture without a major room renovation

**Challenges:**

• No computer access

• Students thought activities were childish, couldn’t access whiteboards, couldn’t access equipment (B Interview 4.17.14, p. 1)

• “Although long tables replaced the original “paddle-type” individual desks in the room, the fixed nature of the seating arrangement caused great difficulties. Students who wanted to avoid probing questions from the instructors simply had to sit in the center of the room, where they were mostly inaccessible.” (FIPSE SCALE-UP 1999 report, p. 3)

o Solution: Move into new classroom, round tables (no specific inspiration for the round tables… At this time, studio physics had long tables along the walls making a single, giant U-shape… email correspondence 1/17/2015), room for instructors to circulate

STAGE 2: 54-student room in Cox (1997-2000)

**Room:**

Flexible seating

Six tables of 9 students (3 groups of 3)

20 laptops in cart (one per group)

No front of the classroom, projection screens

**Curriculum:**

• Continued to develop tangibles and ponderibles in house that became “quick labs” and “quick quizzes” in Beichner-Serway textbook INVENT

• GOAL problem solving- ADAPT- Polya’s steps but gave it a mnemonic name that was easier to remember

• Modified version of UW Tutorials- ADAPT- “must be broken into short segments, with discussion after each part. Before we tried this change in approach we found that it was difficult to keep so many students reasonably “synchronized” during a lengthy tutorial session… We are also seeing if we can have students conduct some of the grading of these materials, not only to reduce instructor effort, but also to encourage higher-order thinking skills” (FIPSE SCALE-UP 1999 report, p. 2)

• Modified version of Peer Instruction (FIPSE SCALE-UP 1999 report, p. 2)- tried using Webassign multiple choice to execute this but it was too klunky (e-mail correspondence 1/15/2015)

• Real World Problem Solving- ADAPT context-rich problems at UMN, ADAPT Activity-Based Physics Thinking Problems created by the University of Maryland PER group and invent some problems in house, ADAPT GOAL problem solving protocol based on Polya, ADOPT CGPS group roles (Interpersonal interactions here with UMN… he doesn’t remember why they didn’t use UMN protocol at this point except they might not have developed it at this point)

**Instructional Practices:**

- Webassign: "encourages students to review the text- book before attending class, provides much needed student practice of simple physics problems, allows for follow-up of in-class assignments to insure that every student has completed the task, and greatly reduces the amount of hand grading. This technology also facilitates in-class polling and permits students to conduct evaluations of each other's work" (B et al. 2008, p. 6)
- Assigned mostly open-ended questions
- Random table homework checks and note checks (since students were concerned about their note-taking skills)
- Extensive laboratory experiments and lab exams "We also have created practical lab exams where each student must demonstrate key skills required for the labs. This insures that everyone gets an opportunity to use the equipment and learn how to take and analyze data." (Beichner et al 2008, p. 16)
- Up to 54 students, students could present their solutions to Real World Problems on quiz days (B et al. 2008, p. 22)

**Successes:**

- "The circular tables are quite effective for promoting group work and encouraging inter-group communication. Students readily work in their own teams of three as well as in table-sized groups of nine. Each table of students seems to become its own little society and develops a unique personality. Stu- dents particularly enjoy having each table work on a problem and then sharing their efforts with the rest of the class by either using the whiteboards that surround the room or by presenting from handheld whiteboards shared within each group. Each student has a nametag (which are color-coded by table for easy distribution) so that no one is anonymous, even in a room with 99 students. One of the strongest reasons that students give for preferring a SCALE-UP class is the ability to work and get to know others in the class" (B et al 2008, p. 26)
- Instructors could reach students
- Faculty-student ratio was large enough that students were assigned almost exclusively open-ended problems (B Interview 4.17.14), grade full lab reports

**Challenges:**

- Tables were too tight for experiments
  - o Switched to 7' tables (after experiments done at NCSU)
- Faculty: student ratios weren't equivalent to large lectures at NCSU
  - o Move to 100-person room
- Too much lab equipment sometimes (Sonic Ranger interference)
  - o Had three-groups at table do slightly different experiments and rotate
- "Explored the possibility of" using Webassign to poll student answers (but it was hard to change answers on the fly)
  - o The invention of clickers solved this problem

**Stage 3: 100-person Room (3a Traditional Curriculum 2000-2004, 3b M&I 2004-current)**

Room

- 99 students seated in three groups of three
- Eleven 7' round tables
- Ceiling mounted projector and document camera
  Wireless microphone for the instructor

Curriculum: Traditional

**M&I**

- B was trying to write textbook (doesn't remember whether there was an interpersonal relation to initially expose him to M&I- email correspondence 1/15/15) it wasn't as good as M&I so he brought Chabay and Sherwood to NCSU to see how it worked with more "normal" students. Reinvent M&I for SCALE-UP- caused b to write out performance outcomes for the first time (B interview 4.17.14).
- Incorporated minimally working programs because of Shawn and Brandon's research
- Adopt/ adapt M&I labs?

**Instructional Practices**

- "We often use individual electronic response units to poll students in class. This allows them to work individually at first to select an answer. After this is completed, the instructor displays a histogram of their choices. If there is disagreement (and there often is), students are given the opportunity to debate with each other and vote again" (B et al. 2008, p. 16)
- "Excel analysis, Java applets (mostly Physlets®), video analysis (using Video- Point) and simulations are a major part of our instructional methodology. In sections using the Matter and Interactions curriculum [see ref. 34], student programming in VPython has nearly replaced simulation development using Interactive Physics software" (Beichner et al 2008, p. 27).
- Tried taking notes on an iPad… students liked the PDFs but he lectured too much- stopped (B interview 4.17.14)

**Successes:**

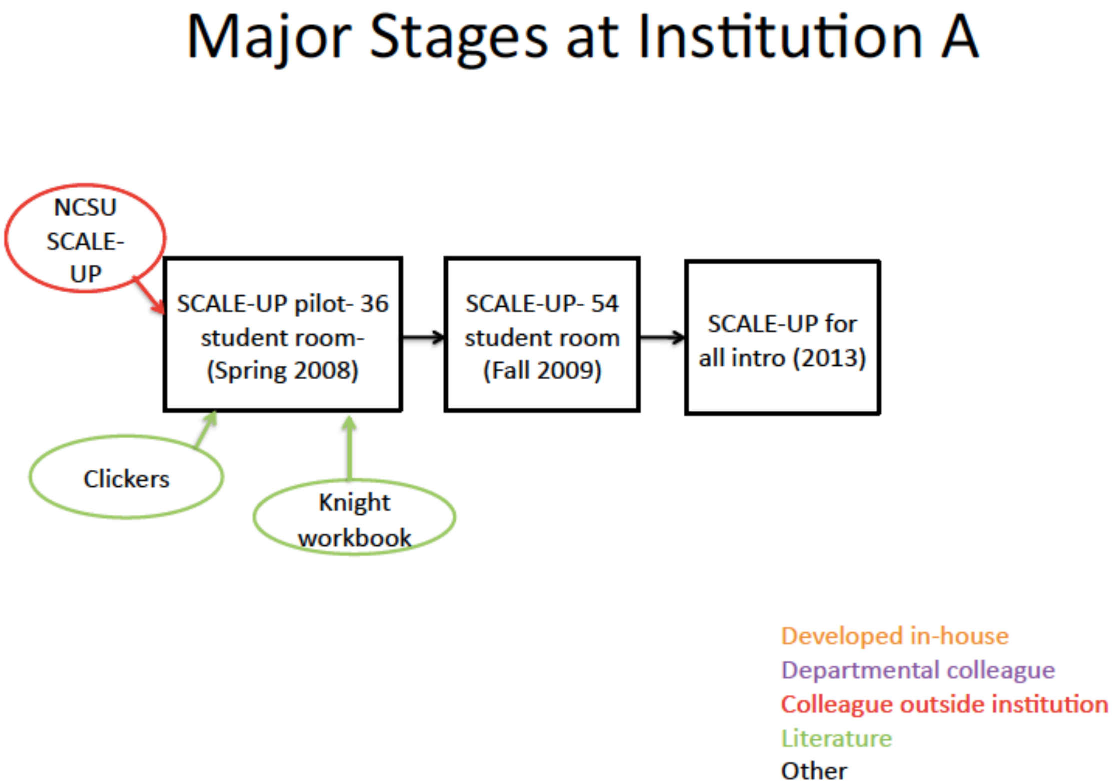
- Successfully has interactive classes for 99 students and 2 instructors
- Switch to M&I and VPython improved Visibles dramatically, had better physics (Beichner interview 4.17.14)
- Traditional curricula was more flexible, could show how things work, more practical applications (Binterview 4.17.14)

**Challenges:**

- Odd-shaped room made it hard for students on the end to see each other (wireless mic makes it easy for everyone to hear instructor- Beichner et al. 2008, p. 26)

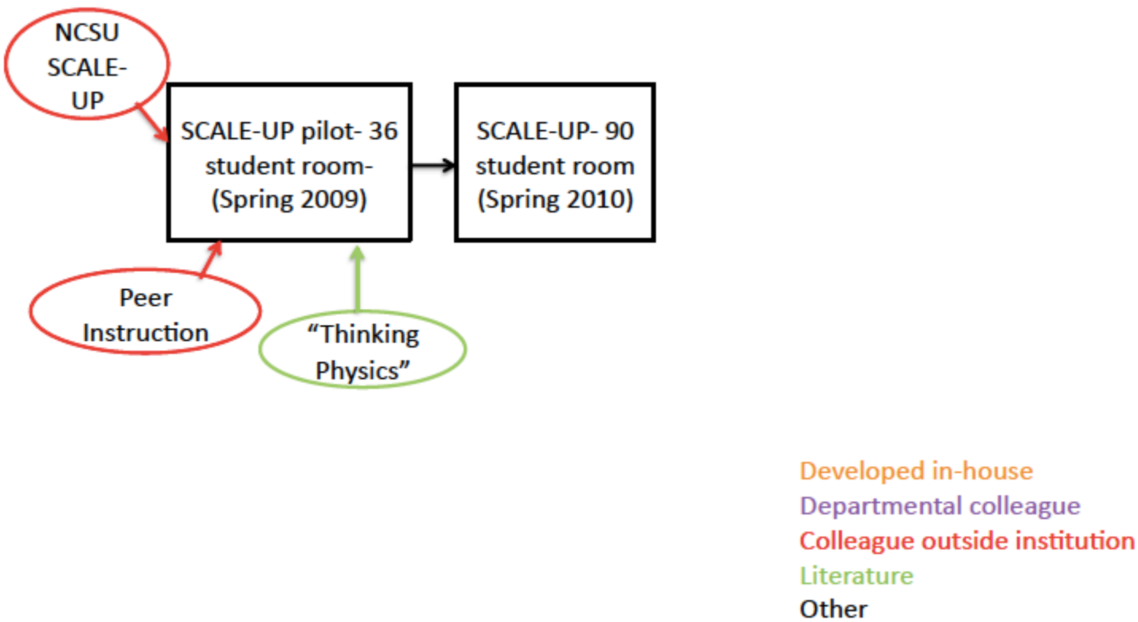
- Lower faculty: student ratio makes open-ended questions harder to grade (eliminated full lab reports at some point)
- M&I curricula made it harder to come up with tangibles (more things happening at the atomic scale), more rigid (since everything builds), (B interview 4.17.14)

**Appendix C: Chapter 4 Timelines**

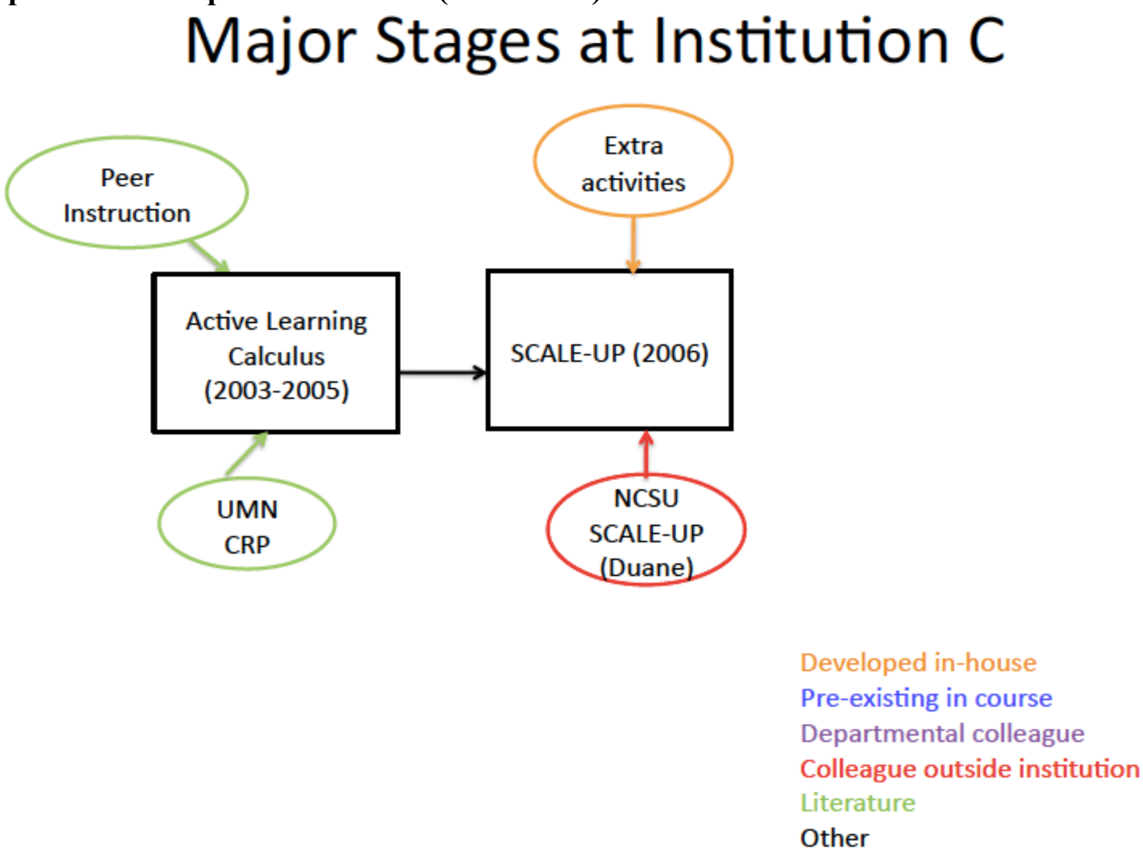


**Appendix C: Chapter 4 Timelines (Continued)**

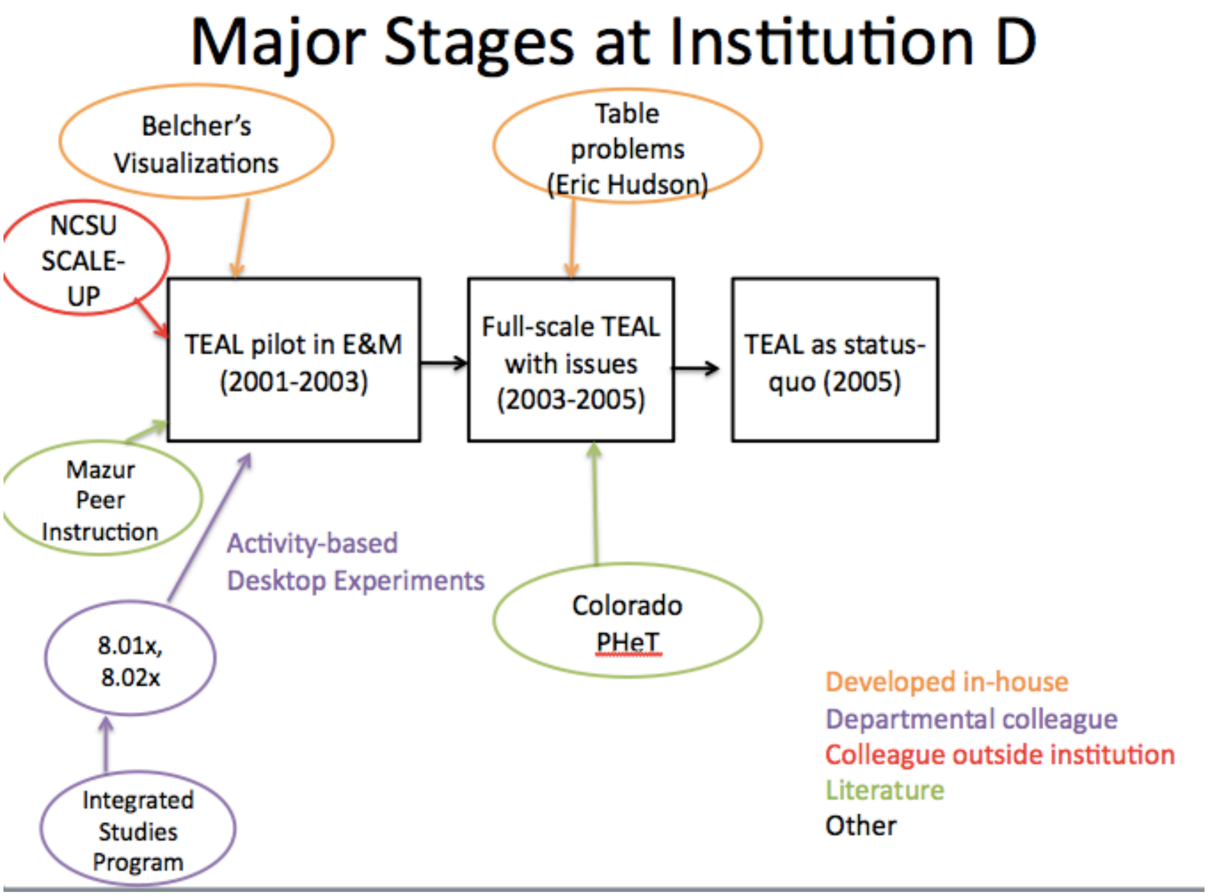
# Major Stages at Institution B



Appendix C: Chapter 4 Timelines (Continued)



**Appendix C: Chapter 4 Timelines (Continued)**



**Appendix C: Chapter 4 Timelines (Continued)**