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A Model for Propagating Educational Innovations in Higher STEM Education: A Grounded Theory Study of Successfully Propagated Innovations

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A MODEL FOR PROPAGATING EDUCATIONAL INNOVATIONS IN HIGHER STEM EDUCATION: A GROUNDED THEORY STUDY OF SUCCESSFULLY PROPAGATED INNOVATIONS

by

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A dissertation submitted to the Graduate College in partial fulfillment of the requirements for the degree of Doctor of Philosophy
Mallinson Institute for Science Education
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A critical problem in undergraduate science, technology, engineering, and mathematics (STEM) education is the slow uptake of innovative teaching strategies and materials. Developments from the STEM education research community can be shown to improve learning and retention outcomes, but the majority of new teaching strategies go unused by instructors. This problem is increasingly acknowledged by funding agencies such as the National Science Foundation, which now calls for “transferability and propagation” to be addressed throughout a project’s lifetime in the request for proposals. However, few publications synthesize what is known about propagating innovations into usable, actionable recommendations for developers in the context of STEM education. The overall goal of this work is to help understand how to improve adoption/adaptation of evidence-based educational innovations from the standpoint of innovation developers. This study uses a grounded theory design, building theory about a process, “grounded” in the data (Creswell, 2007; Strauss & Corbin, 1998). The study has three main components: constructing a “baseline” understanding of typical propagation practice, understanding highly successful practice, and refining the initial theory with more targeted investigations of successful practice. Data is analyzed continually comparing and elaborating on prior analysis through the constant comparative method. Typical practice is studied through qualitative survey results from over 1200 NSF principal investigators, and through focus group
data with the eight disciplinary groups of NSF program directors of (what was) the Transforming Undergraduate Education in STEM program. Successful practice is studied through identifying and broadly characterizing 41 successful innovations, then delving into detailed case studies of three of those (Peer-Led Team Learning, Peer Instruction, and the PhET Interactive Simulations.) The final refinement phase builds on the model through 11 additional cases. Interactivity with potential adopters at all stages of the project underlies the success of well-propagated innovations: for example, gaining feedback from users early in the project and having active collaborations, using dissemination mechanisms such as immersive workshops, and personally answering questions when adopters are implementing the innovation. This study fills an important gap in the literature on change in STEM education, providing developers of education innovations with recommendations to plan for propagation.
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Raina Khatri
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CHAPTER I

INTRODUCTION

Background

In undergraduate STEM education research, it is widely acknowledged that many commonly-used teaching practices lead to poor learning and retention outcomes for students, in particular for groups such as women and minorities (Johnson, 2007; Seymour & Hewitt, 1997). Typical classroom settings such as large lecture halls and little opportunity for direct engagement with the material during class time leads to student dissatisfaction with STEM courses and ultimately poor student outcomes. One important result of poor STEM teaching practices is that fewer than 40% of students entering college with an intention to major in a STEM field complete a STEM degree (The President’s Council of Advisors on Science and Technology, 2012).

To combat these learning and retention issues, STEM education researchers have developed many new teaching strategies and materials (National Research Council, 2012). Recommendations for research-based pedagogy in undergraduate science classrooms are based on what is known about learning (Bransford, Brown, & Cocking, 2000; Fox & Hackerman, 2003). This overall shift can be articulated as a move to a “learning paradigm” from the more traditional “teaching paradigm” (Barr & Tagg, 1995). Newer teaching strategies, in alignment with literature on learning, feature a shift to student-centered (as opposed to instructor-centered) instruction and alternatives to the typical lecture mode by providing different activities to foster engagement with the content, often inductively, often featuring a cooperative peer interaction component (Brewer & Smith, 2009; Prince & Felder, 2006). These teaching strategies and materials can be shown to improve student learning and experiences in the classroom (Committee on Undergraduate Physics Education Research and Implementation, 2013; Graham, 2012; Prince & Felder, 2006).

Despite the evidence that research-based teaching strategies can improve student learning and retention, undergraduate science instruction has yet to see widespread change to the student-
centered, research-based learning paradigm. New teaching strategies and materials are not being widely used, and over the past few decades, numerous national reports and initiatives have pushed for large-scale change in undergraduate science teaching to use research-based teaching strategies (e.g., Brewer & Smith, 2009; Project Kaleidoscope, 2002; The President’s Council of Advisors on Science and Technology, 2012). Despite the known problems of student retention, solutions of new teaching strategies, and pressure from national societies and funding agencies, these strategies are still not being widely used (Brewer & Smith, 2009; Handelsman et al., 2004; Kezar, 2012).

A review of journal articles regarding change strategies in higher education found that STEM education researchers tend to think about change in terms of a “develop and disseminate” framework—that is, researchers develop a new teaching strategy or material and then make other instructors aware of the innovation, with the expectation that others will use it (Henderson, Beach, & Finkelstein, 2011). This develop and disseminate framework is the reality for STEM education researchers applying for funding from agencies such as the National Science Foundation, since most funding for education research expects grant recipients to develop a new educational innovation during the 3-5 year grant period (Seymour, 2001). Grant recipients then publish articles and present their work at conferences to inform other researchers of the work (Tront, Mcmartin, & Muramatsu, 2011). The current solicitation for the NSF Improving Undergraduate STEM Education (IUSE) program states “transferability and propagation are critical aspects for IUSE-supported efforts and should be addressed throughout a project's lifetime….” (National Science Foundation, 2016). STEM education researchers have been churning out new strategies and materials for decades but the issue of propagation remains harder to accomplish, despite it being a stated goal.

This is not a problem of instructor awareness of new teaching strategies. Research indicates that instructors are aware of new teaching strategies, but either do not try them or discontinue use after a trial period (Borrego, Froyd, & Hall, 2010; Henderson, Dancy, & Niewiadomska-Bugaj, 2012). Additionally, instructors may be aware of new strategies but alter them substantially from the original, research-based version, in which case the strategy may no longer be effective (Henderson & Dancy, 2009). While the develop and disseminate model works for developing new strategies and raising awareness of them, it does not result in positive
implementation outcomes (Fixsen, Naoom, Blase, Friedman, & Wallace, 2005). What is needed are ways to encourage sustained use rather than merely awareness and initial trial.

Problem Statement

Little work has been done to identify practices for STEM education researchers to effectively propagate new educational innovations within the develop and disseminate change strategy. For this specific audience of change agents (people who actively work toward change in their organization or institution), there are reports based on conferences and workshops with experts (e.g., Litzinger et al., 2011) but little empirical research supports these recommendations. Beyond the limited literature base targeted toward this problem, much is known about diffusion of innovations (e.g., Rogers, 2003), organizational change (e.g., Kezar, 2001), the levers and barriers involved in adopting/adapting innovations (e.g., Dancy & Henderson, 2008; Henderson & Dancy, 2007, 2008), and various factors and mechanisms that foster successful dissemination and implementation (e.g., Bourrie, Cegielski, Jones-Farmer, & Sankar, 2014; Fincher, 2000; Fixsen et al., 2005; Foertsch, Millar, Squire, & Gunter, 1997; Gafney & Varma-Nelson, 2008; Gannaway, Hinton, Berry, & Moore, 2011; Hazen, Wu, & Sankar, 2012; Hutchinson & Huberman, 1994). But, this literature does not indicate a coherent, actionable set of practices for STEM education developers to follow.

Research Goal

To address this gap in the literature, I propose a qualitative study to develop a model of designing innovations for successful propagation that can help education developers construct propagation plans leading to sustained adoption of educational innovations. While much is known about the process of adoption of innovations in general (Rogers, 2003) and common barriers to propagation (e.g., Dancy & Henderson, 2008), less is understood about the practices of education developers that lead to sustained adoption of innovations within the specific context of funded projects in undergraduate STEM instruction. The goal of this work is to develop a better understanding of the practices that lead to successful propagation. The outcome of the work is a model of designing innovations for successful propagation within the context of higher STEM education.
Conceptual Frameworks

This study draws upon three conceptual areas: 1) how change agents in STEM education think about change, 2) what is known about dissemination strategies to encourage the use of evidence-based reforms and 3) the instructional system context. The first provides the situating framework to examine the literature from the viewpoint of education developers.

Situating Framework: How do Change Agents in STEM Education Think about Change?

A large review of change strategy literature in higher education divides the literature base into four main change strategies: 1) disseminating curriculum and pedagogy, 2) developing reflective teachers, 3) developing policy, and 4) developing shared vision (Henderson et al., 2011). In STEM education, researchers and curriculum developers most commonly work within the first category, which typically involves developing promising new curricular materials and/or teaching strategies and making them available to other instructors with the intent that they will be used. Change agents in STEM are often implicitly guided by this change strategy (Borrego & Henderson, 2014), thus making it appropriate for use as the overall situating framework for the current study.

What is Known about Dissemination?

Rogers (2003) is widely known for his work on the diffusion of innovations. His *innovation-decision process* describes stages adopters move through as they decide to adopt (or not adopt) an innovation. The stages are:

1. Knowledge: Potential adopters become aware of the innovation and learn a little about it
2. Persuasion: Potential adopters gain enough information to form an opinion (positive or negative) about the innovation
3. Decision: Potential adopters choose to adopt or not adopt the innovation
4. Implementation: Potential adopters try the innovation, putting it into place
5. Confirmation: The adopter considers the decision to try the innovation and either continues or discontinues use
This breakdown of specific stages has been used in STEM education research to describe the decision process of instructors adopting (or not adopting) innovations. Borrego and colleagues (2010) utilized this framework in a survey of engineering department chairs in the US; they found that 82% of those surveyed were aware of various evidence-based instructional strategies, but only 47% said those strategies had been adopted by their departments. A similar study of physics faculty found that a third of faculty who try an innovation discontinue use, dropping out of the innovation-decision process at the confirmation stage (Henderson, Dancy, et al., 2012). A white paper synthesizing these results (and another similar study from the geosciences) concludes that raising awareness among instructors of new teaching strategies is not the problem, but rather encouraging sustained use is (Henderson & Dancy, 2011).

Frameworks describing the dissemination of STEM education innovations have been developed to synthesize the knowledge base, describing the process of adoption and identifying factors important to successful dissemination (Bourrie et al., 2014; Hazen, Wu, Sankar, & Jones-Farmer, 2012; Hinton, Gannaway, Berry, & Moore, 2011). They utilize the stages from Rogers (2003) and emphasize the importance of tailoring dissemination materials to where a potential adopter is in their innovation-decision process (Froyd, 2001; Hazen, Wu, Sankar, et al., 2012; Hinton et al., 2011). For example, flyers can raise awareness, and workshops function to provide additional information to already-interested potential adopters (Foertsch et al., 1997; Froyd, 2001; Litzinger et al., 2011). An important takeaway from this work is that education developers and change agents need to interact with instructors based on where the instructors are in the innovation-decision process.

One factor thought to be important when choosing dissemination strategies is the type of innovation (Cuban, 1999; Fixsen et al., 2005; Henderson, Cole, Froyd, & Khatri, 2012). For example, a material that an individual instructor can adopt for free and without the need to involve other individuals at their institution will be adopted more easily than something requiring resources such as money and institutional space (Froyd & Borrego, 2010). In addition to considering where a potential adopter is in their decision process, strategies should consider the type of innovation as well.

Another factor is personal interaction with potential adopters. Early in a project, interaction can provide feedback on the innovation (Blank & Dorf, 2012; Hinton et al., 2011), and it is known that frequent communication between implementation sites and the original
developers leads to better implementation outcomes (Fixsen et al., 2005; Henderson et al., 2011; Hutchinson & Huberman, 1994).

The important message from these bodies of work is that successful dissemination involves much more than developing a good product and getting the word out.

The Instructional System Context

Instructional change happens within a larger system that must be understood. The instructional system as articulated by Lattuca and Stark (2009) situates change in higher education within a sociocultural context, with the factors of internal influences (such as the institutional/departmental culture and resources and student characteristics), and external influences (such as market forces, government agencies, disciplinary bodies, and accrediting agencies.) This framing of the instructional system was created with the intention to make explicit the complexity of adopting educational innovations and can be applied to instructors’ individual decision making processes (Lattuca, 2011). The important message is that all parts of the system must be considered.

Literature Review

This section examines literature regarding the instructional system and known dissemination strategies.

Known Dissemination Strategies

Frameworks for Successful Dissemination in STEM Education

Several groups of researchers have done work to understand the process of successful dissemination of educational innovations in STEM, generating frameworks of dissemination (Bourrie et al., 2014; Gannaway et al., 2011; Hazen, Wu, Sankar, et al., 2012; Hinton et al., 2011). These provide insight into factors for dissemination success.

The D-Cubed guide to effective dissemination is a comprehensive planning guide for education projects in Australia to plan for dissemination (Gannaway et al., 2011; Hinton et al., 2011). It is the product of multiple successive studies of project outcomes, looking to successfully disseminated projects in particular for their characteristics. Much of the D-Cubed
framework incorporates a wide systems view of dissemination, beyond a project team or individual adopters, to fostering a nationwide attitude toward change. Their framework has three main aspects: assessing the climate for change (making sure there is a need for the innovation in the contexts where it should be adopted), enabling transfer of outcomes (making the innovation available and easy to find), and engaging throughout the project (interacting with potential adopters frequently).

Bourrie et al. (2014) conducted a Delphi study of experts (individuals who received NSF funding in STEM education) to determine the characteristics of several factors affecting dissemination: educational innovations, characteristics of students, characteristics of faculty members, and of administrators. Their framework describes characteristics of educational innovations that lead to their successful dissemination, such as ease of use and relative advantage (Rogers, 2003).

Hazen et al. (2012) conducted a theoretical study, drawing upon literature in the area of dissemination of educational innovations and diffusion theory (Rogers, 2003) to construct a framework. Their research objective was to develop a framework and research agenda going forward in the area of educational innovation dissemination. Their framework describes the stages of adoption as intent to adopt, adoption, and routine use, and they suggest that the characteristics of the adopters and the environment will influence adoption at each stage.

These frameworks provide insight into the process of dissemination and the factors affecting it, synthesizing the literature with several major insights: aspects of an innovation itself will impact dissemination, as will characteristics of the instructional environment.

Strategies for Dissemination

Foertsch et al., (1997) conducted an empirical study of four different dissemination techniques for innovative teaching strategies and materials. The approaches were, in order of least to most interactivity with the participants: 1) unsolicited mailings of materials, 2) website postings where participants could choose to order the materials, 3) seminar presentations given by people who developed/were using the reform with mailings of the materials following the presentation, and 4) face-to-face several hours long “mini-courses” or workshops given by developers in which they handed out the materials personally. The researchers sampled from the participants exposed to each approach and interviewed them about their perceptions of the
materials and thoughts about whether they would consider the new instructional practices they outlined.

They found that sending unsolicited mailings of materials had different effects on participants. The materials were too detailed for some, while for others who were far along the adoption process with a reform they were already interested in, the concept was “uninteresting” because it was too similar. The researchers describe the place between as the “reachable moment” in which potential adopters would consider the reform. When participants had requested mailings or listened to a seminar about the instructional materials, they were in a “reachable moment.” This was seen in the data regarding the mini-courses as well: the mini-courses best served the needs of faculty who were already considering using the reform and needed to learn more about it; however, the courses were too short and not informative enough for those who had already decided to adopt the reform. While it might seem that the “best” methods of dissemination are the most interactive, this study adds to the idea that many approaches are necessary to guide potential adopters through the process from awareness to adoption, with less intensive/interactive ones toward the beginning, with interactive and highly informative approaches becoming more useful toward the end.

Another report toward generating strategies for developers was the product of an intensive conference of experts (such as NSF program directors and experienced researchers in changing higher education) and stakeholders (such as department heads and graduate students), with an interdisciplinary makeup of individuals from engineering education and psychology. The focus of the conference was to improve the writing of both evaluation and dissemination plans in NSF proposals, so the focus was not entirely on dissemination. However, the evaluation of a product could form part of interactive development and making a transferable product; indeed, one of the findings in this report is that the dissemination plan and evaluation plan should be linked.

Dissemination methods are given in this report framed as what materials would be most helpful in a potential adopter’s decision process—for developing awareness, a flyer or short video can be effective, and for helping make a decision on adopting, a short workshop could be useful. For the leap into adopting, longer workshops and specific tools such as lesson plans are most helpful. This is in alignment with Foertsch et al. (1997) regarding the “reachable
moment”—for instructors who already wanted to adopt a reform, short workshops were not enough, and they would have benefitted from a longer workshop with more specific tools.

Creating quality dissemination materials can go a long way toward forming favorable impressions of educational innovations. Besides the findings from Foertsch et al. (1997), some other aspects instructors prefer are that materials should be short, to the point, with no jargon, and with references (Kezar, 2000). One valuable resource in K-12 dissemination planning is the book “Designing Professional Development for Teachers of Science and Mathematics” by Loucks-Horsley and colleagues (2010). It has been used widely and is prominent in professional development literature (2966 citations, according to Google Scholar.) It summarizes much of the available literature on teacher professional development, incorporating literature on learning. The authors point out that at the time of the first publication of the book, while designers and teachers they worked with knew how people learned, little of that knowledge was present in professional development techniques (Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2010, p. 53).

Many techniques outlined in the book are intended for developing deeper content knowledge and reflective practice; for example, action research (in which teachers are invited to conduct their own research at the local level) and demonstration/observation by other local instructors. For specific innovations that a developer in STEM education might want to propagate, there are three strategies in particular that could be useful: case discussion; workshops, institutes, and seminars; and online professional development.

Case discussion is a strategy based around presenting a given narrative intended to illustrate a specific concept or issue, inviting discussion. A case can offer a chance to discuss hypothetical situations a teacher might encounter, with peer ideas on how to handle those situations. The materials must be “…focused on a specific aspect of teaching or learning[…] be facilitated by a knowledgeable and experienced facilitator [and be] relevant and recognizable” (2010, p. 218).

Workshops, institutes, and seminars are focused experiences on learning a specific instructional strategy. The authors caution that these formats for professional development are often rife with ineffective teaching strategies, and lay out several features for a successful experience: the goals of the workshop must be clear, time must be used effectively, the facilitators should be experienced, and opportunity should be provided for networking. They also say that one-time experiences “are unlikely to result in significant, long-term changes” and that
“50 hours or more of professional learning experiences are required to impact teaching practices” (2010, p. 265).

Online professional development is an avenue for reaching large groups of teachers, and again the authors offer guidelines to enhance these experiences. They advocate for group sizes appropriate to the format of learning (large groups are approached through webinars and online courses, while smaller groups might be better served with resources online that they then discuss in person). Like the other two strategies, they suggest that the facilitators of the chosen format should be experienced, and the technology itself must not serve as a lagging distraction. Finally, they say that “mechanisms for reflection” should be established, such as “real-time discussions or reflective entries posted online” (2010, p. 275).

The common aspects of all these activities are opportunities for reflection, quality materials, and quality facilitation. Further, these professional development strategies cannot be one-time only events, but rather need an element of follow-up.

Known Dissemination Strategies: Conclusion

Several frameworks have been developed in STEM education to address the lack of uptake of research-based reforms. They draw upon diffusion literature and establish characteristics of innovations that lead to successful dissemination; for example, the innovation fills a need. One framework also has a main component of engaging adopters frequently throughout the project.

The literature on dissemination methods suggests that methods should match where an adopter is in their innovation-decision process. There is also literature on crafting professional development experiences for instructors.

The Instructional System

The factors influencing the instructional system affect how and whether new teaching strategies and materials will be implemented (Bourrie et al., 2014; Lattuca, 2011). This section explores the literature relating to individual instructor, departmental, institutional, and disciplinary factors and their influence on adopting educational innovations.
Individual Instructor Beliefs

A common idea in the change literature at the individual level is that before change can happen, individuals need to be dissatisfied with the current state of affairs. This can be referred to as creating a climate for change (Hinton et al., 2011), creating a sense of urgency (Kotter, 1996), finding the feeling (Heath & Heath, 2010), or establishing dissatisfaction with current practice (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003). In essence, if people do not see a need to change, then the effort of implementing some new reform appears to be superfluous or a waste of time. Change agents who want everyone around them to change and are frustrated with inaction might blame laziness or some other negative human element, but literature indicates that dissatisfaction with current practice is essential to instructors changing their thinking about teaching.

The good news for change agents is that many instructors are already dissatisfied with lecture, at least in physics (Turpen, Dancy, & Henderson, 2010, 2016). In a study of instructors who use Peer Instruction, participants were asked how they came to know about Peer Instruction and why they were motivated to try using it. One of the reasons they wanted to try it was because they know that lecture does not appear to be the best teaching method, and Peer Instruction seemed like a transition from pure lecture to a more interactive classroom. Their dissatisfaction with current practices assisted in trying a new instructional strategy.

However, the bad news for change agents is that not all instructors are dissatisfied with the way they teach or teaching practices of their colleagues at large. One strategy of education developers has been to collect data about the effectiveness of their innovation in order to persuade other instructors that it is a promising option—however, literature indicates that instructors who do not already want to change practices are not convinced by evidence of effectiveness (Austin, 2011; Fairweather, 2008). Therefore, in addition to demonstrating that the new instructional strategy is indeed effective, other strategies are needed to create a sense of dissatisfaction.

Specifically targeting instructor conceptions of teaching can lead to successful changes (Henderson et al., 2011). An intervention to specifically change conceptions resulted in some instructors rethinking teaching. One study of three instructors implementing a new reform (with the three instructors respectively experiencing no dissatisfaction, dissatisfaction in the past, or
current dissatisfaction with their teaching practices) found that dissatisfaction was the product of seeing a disparity in their own ideal vs. their reality in practice (Gess-Newsome et al., 2003).

There are many individual instructor characteristics that can influence decisions about adopting an educational innovation. In a study looking at instructor use of research-based instructional strategies, some characteristics that correlated with high use were attendance at professional development opportunities (in this study, the New Faculty Workshop in physics), satisfaction that as instructors they were meeting their instructional goals for students, and gender (female instructors were more likely to use new instructional strategies than males) (Henderson, Dancy, & Niewiadomska-Bugaj, 2010). Other possible characteristics are where someone is in their career, whether an instructor is tenure-track or an adjunct, and their prior experience with teaching (Austin, 2011).

Much work has been done examining the barriers that instructors report to their ability to adopt research-based instructional strategies (e.g., Froyd, Borrego, Cutler, Henderson, & Prince, 2013; Henderson & Dancy, 2007). Predictably and overwhelmingly, time is a frequently mentioned barrier to changing teaching practices (e.g., Fairweather, 2008; Foote, Knaub, Henderson, Dancy, & Beichner, 2016; Gess-Newsome et al., 2003; Henderson & Dancy, 2007; Khatri et al., 2016; Seymour, Dewelde, & Fry, 2011; Turpen et al., 2016). Resources, like institutional space and funding, are also difficult to obtain. While education developers creating a new reform (usually) have access to time and resources due to their funding, the same is not true of their potential adopters. Further, adopters may have concerns about whether an innovation created at another institution could work at one like theirs (“not invented here” syndrome) (Borrego et al., 2010; Froyd, King, Litzinger, Seymour, & Chairs, 2011), and may have issues with student resistance, which can then reflect poorly upon them. There are increasing calls for developers to assuage these barriers.

It should be noted that while much emphasis in the literature has been on barriers that individual adopters face, there are also some potential levers, or positive motivations, for instructors. Instructors who tried using Peer Instruction in their classrooms reported several affordances such as personal success with the innovation quickly upon using it, and seeing how the innovation engaged students (Turpen et al., 2016).
Departmental Factors

The more cooperation and resources that an innovation needs in order to be adopted, the more the department will need to be involved (Foote et al., 2016; Stanford et al., 2017). The department plays a significant role in helping or hindering change efforts. An individual instructor is influenced by the department in several ways: the courses they will teach, whether teaching factors into tenure decisions, whether teaching in a certain way is valued (Austin, 2011). In addition, the curriculum and sequence of courses are determined by the department (Austin, 2011). Individual instructors work within these departmental-set conditions for courses and how their performance will be evaluated.

However, similar to institutional influences, departmental influences need not necessarily be viewed as all barriers—they could also serve as levers (Austin, 2011). A department showing they value teaching through their reward systems and workload allocation decisions could encourage changed teaching practices.

Research on reforming STEM departments indicates that departmental attitude toward teaching and toward the reform effort itself affects the outcome, and there are indications that departments wholly engaged in changing teaching practices can more easily accomplish it (Wieman, Perkins, & Gilbert, 2010). A study of five departments undergoing change at a single university (and thus holding institutional factors constant across departments) examined the processes of change at each department (Fisher & Henderson, n.d.). The study framed change as either prescribed or emergent, using Kotter’s Eight-Step model to specify prescribed stages and Complexity Leadership Theory to describe emergent stages. Both models of change share four key stages, used to analyze the activities of the departments: creating a vision, motivating participants, building momentum, and institutionalizing change. Open communication, clear expectations, and public recognition of successes underlie the effective activities using either the prescribed or emergent approach.

Institutional Characteristics

Institutional characteristics can pose barriers or function as levers in change initiatives. In a study of physics instructors, the instructors were aware of and held favorable views toward novel teaching methods, but noted they themselves did not practice those teaching methods.
They attributed the differences to local factors beyond their control: class size, student resistance, limited instructor time to implement new methods, inflexible class meeting times, and classroom structure (Henderson & Dancy, 2007).

Another possible barrier is the need for cooperation between departments or different colleges within an institution (Stanford et al., 2017). In the study of physics instructors, expectation of content coverage was suggested as another barrier (Henderson & Dancy, 2007). Content can be dictated by multiple departments, especially in the form of prerequisites; for example, the physics department would expect certain topics to be covered in calculus courses in the mathematics department.

Literature indicates that faculty decisions about teaching are influenced by their institutional context (Austin, 2011; Lund & Stains, 2015). Change initiatives that are aligned with an institution’s culture are more successful than those that challenge the current culture (Kezar & Eckel, 2002b; Merton, Froyd, Clark, & Richardson, 2009). In one study of implementations of an educational innovation, change agents at an institution were able to overcome cultural issues by establishing a need to change or incentives, such as increasing institutional prestige, appealing to institutional decision-makers (Foote et al., 2016), strategies aligned with change literature on creating a discontentment with how things are usually done to create a “climate for change” (Heath & Heath, 2010; Hinton et al., 2011). However, institutions where the culture already supported active teaching listed this as an enabling factor in implementing and sustaining the innovation.

The culture is not always a barrier; it could be that identifying how the culture works can lead to identifying change strategies, to make the change strategy align with the culture instead of making the culture align with the change strategy (Henderson, Cole, et al., 2012; Kezar & Eckel, 2002b).

Disciplinary Differences

While the institution and the department an instructor teaches in shapes many aspects of their teaching decisions, so does the discipline to which they belong. NSF TUES program directors in different disciplines (biology, chemistry, computer science, engineering, geoscience, mathematics, physics and interdisciplinary) believed their disciplines faced issues with propagation unique to their field, speaking about how the size, culture, and structure of their field
impacted the uptake of results from education research relative to other fields (Khatri, Henderson, Cole, & Froyd, 2013). For example, the engineering program directors believed the size of their discipline (with their many subdisciplines) prohibitive in disseminating information, and the biology program directors noted that they did not have a centralized professional society like physics does.

A survey of faculty regarding goals in undergraduate teaching revealed that instructors in “hard” disciplines placed more importance on teaching students to apply concepts to their possible career than did “soft” discipline instructors, and more importance is placed on acquiring vs. applying knowledge in “pure” vs. “applied” fields (Smart & Ethington, 1995). These factors influence the norms of what content is usually taught in each discipline, and the goals each discipline intends for student learning.

Another study splitting fields into “hard” and “soft” found that the “hard” discipline instructors were more teacher-centered (i.e., focused on lectures in a large hall) and “soft” disciplines were more student centered (with more interaction with students) (Lindblom-Ylanne, Trigwell, Nevgi, & Ashwin, 2006). This matches the general stereotype of how STEM courses are taught vs. how humanities are taught, which is thought to be a factor in student dissatisfaction with STEM courses compared to their other courses (Seymour & Hewitt, 1997).

In a study of biology, chemistry, and physics faculty at a single institution to understand the influences to adopt or not adopt research-based instructional strategies, disciplinary differences existed even though they all taught at the same institution (Lund & Stains, 2015). While faculty in the three disciplines were aware of instructional strategies from education research at roughly equal levels, physics instructors used them the most, followed by biology, then chemistry. These adoption rates corresponded with the views of faculty as to whether their discipline supported the use of these instructional strategies; physics faculty felt more supported in decisions to try new strategies at a departmental and extra-institutional level while biology faculty mentioned a mix of support and barriers, and chemistry faculty discussed a lack of support. This includes opportunity for professional development: physics faculty had some prior involvement with workshops or other teaching opportunities, whereas chemistry faculty did not have the same training opportunities. Lund and Stains caution, “…studies of faculty in one particular STEM discipline within one particular type of institution may not generalize well to all STEM faculty at all institutions” (Lund & Stains, 2015, p. 17).
Instructional System Conclusions

Aspects of the instructional system are often neglected in propagation plans (Stanford et al., 2017), but each component matters with regard to adopting educational innovations. The nature of an innovation interacts with the many instructional system factors. The institutional culture and local factors impacts if a change strategy can be implemented. The department influences instructor workloads, class size, and other local factors, and has a culture within the institutional culture. Disciplinary differences can impact individual instructor decisions as teaching strategies align with or go against disciplinary norms—and some disciplines might support change while others are less supportive.

Literature Review Summary

Much of the research into dissemination of educational materials discusses the barriers (and more rarely, levers) that exist in the instructional system: issues such as faculty workload and therefore time to adopt new teaching strategies, the faculty rewards system, institutional culture, and departmental climate (e.g., Austin, 2011; Cuban, 1999; Dancy & Henderson, 2008; Fairweather, 2008; Kezar & Eckel, 2002). This provides food for thought for funding agencies, accrediting bodies, and other forces potentially in positions of power to address or circumvent these barriers, but what this body of literature lacks are concrete strategies for developers of new teaching strategies and materials to encourage broad, sustained use of their work. Some publications offer guidance on the dissemination process (e.g., Hinton et al., 2011; Bourrie et al., 2014; Hazen et al., 2012) and dissemination methods (e.g. Litzinger et al., 2011; Foerstch et al., 1997) but it is clear that dissemination itself is not the problem, as instructors are aware of new teaching strategies, but often do not use them (e.g. Henderson et al., 2012; Borrego et al., 2010).

Research Questions

To address this gap in the literature, work is needed to understand both the typical practices of education developers and the practices of successful education developers, to identify strategies developers can use to plan for and support broad, sustained use of their products by other instructors. The overall goal of this project is to develop a better understanding
of propagation practices that lead to the successful adoption of STEM educational innovations. This overall goal will be addressed by the following research questions:

1. Which STEM education innovations are widely adopted? Are there factors and/or features common to instructional strategies that are widely used? How do these compare to those in typical propagation practice?
2. What are the differences between typical and successful propagation practices?
   - What propagation activities are seen in typical practice? How do typical NSF principal investigators think about propagation? How do NSF program directors think about propagation?
   - What propagation activities are seen in successful practice? How do successful project teams think about propagation?
3. How do successful projects engage with potential adopters? How can developers determine adopter’s support needs? What mechanisms do successful projects use to provide support for adopters?

Methodology

Qualitative methods are an appropriate choice to address these research questions. Grounded theory guides the overall design of this study; this methodology is suited for describing a process, developing a theory that fits the data (Corbin & Strauss, 2014; Creswell, 2007). In contrast to studies that begin with a hypothesis (and thus a preconceived answer to the research question), grounded theory studies typically begin with an open-ended research goal or question (in this case, develop a better understanding of the propagation practices that lead to successful adoption) (Corbin & Strauss, 2014; Gibson & Hartman, 2014; Wasserman, Clair, & Wilson, 2009). Data is analyzed continuously as it is collected, comparing with previously analyzed data using the constant comparative method, and choice of data sources is determined by theoretical sampling to inform the emerging theory (Corbin & Strauss, 2014; Miles & Huberman, 1994; Suddaby, 2006; Wasserman et al., 2009).

This section will discuss grounded theory methodology and its application to this study, then describe the sources of data and the analysis procedures for the study.
Grounded Theory Methodology

Grounded theory was developed by Glaser and Strauss in the 1960s in response to a problem in sociology in which there was little connection between data collection and theory creation (Gibson & Hartman, 2014); hence, “grounding” new theories in data. Instead of assuming an outcome through establishing and testing a hypothesis, grounded theory allows for unexpected outcomes. Two key features of grounded theory, the constant comparative method and theoretical sampling, are concepts that “violate long-standing positivist assumptions about how the research process should work” (Suddaby, 2006, p. 634). While scientists learn in statistics class that populations should be representative of the general population in order to generalize results, grounded theory does not share this idea, instead targeting the specific data sources that are necessary for building a theory for a specific process or experience. Much grounded theory work explores human experiences, for example: living with pain, exploring gender nonconformity, and dealing with loss (Corbin & Strauss, 2014; Gibson & Hartman, 2014).

Despite the thoroughly-described beginning of grounded theory in Glaser and Strauss’ 1967 book, Discovery of Grounded Theory, and later texts such as Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory by Strauss and Corbin (1990, 2014) that explain the procedures of the methodology at length, there is a great deal of argument and confusion about what constitutes a grounded theory study. First, there are two main schools of grounded theorists: as Creswell (2007) puts it, the “systematic” procedures of Strauss and Corbin (1990, 2014) and the constructivist approach (Charmaz, 2006). Charmaz (2006) established this new version of grounded theory to align the methodology more with the viewpoint of participants, creating theory collaboratively and focusing on the meaning for participants. The “systematic” version of grounded theory puts emphasis on how the data is analyzed (using open, axial, and selective coding). Methodology authors in both camps can be adamant about what is and is not a grounded theory study (Gibson & Hartman, 2014; Suddaby, 2006).

Aspects of grounded theory are often considered vital by some and flexible by others. For example, it is a question in the literature, even among experts, how much background reading a researcher should have already done in the area prior to conducting the study. Suddaby and colleagues (2006) state that “grounded theory is not an excuse to ignore the literature” (pg. 634),
because researchers often state that they need to not have read anything so they can build theory directly from the data and not preconceived notions. However, that is precisely what Strauss and Corbin (1998) advocate doing, having some familiarity but not extended reading: “…the researcher does not want to be so steeped in the literature that he or she is constrained and even stifled by it” (pg. 49). Gibson and Hartman (2014) in their synthesis on grounded theory methodology posit that the original reading of the 1967 text would say the researcher should already be familiar with main theories in the area, but not specific literature. These are three interpretations of the same text, leading to three different conclusions.

Given the disagreement among experts, is not useful (or, indeed, possible) to make sure that every aspect of a study exactly follows the procedures in either the systematic or constructivist approach. Gibson and Hartman (2014) summarize the main tenets of grounded theory neatly:

1. Openness – the research question should be open, and the researcher should be aware of preconceptions.
2. Explanatory power – the theory has to work, fitting the data, and be relevant to the people it concerns.
3. Generation vs. justification – the theory is created from data, and is adjusted to fit new data.
4. Theory structure – the theory should be composed of propositions relating to a core category and with sub-categories that provide more detail.
5. The research process – data is analyzed as it is gathered, and analysis should involve three stages: open, selective, and theoretical coding.

Again, with the disagreement from experts on nearly all these points in some way or another, these points should be taken to be guidelines and not an exact roadmap. Particularly in the areas of management, organizational and educational change, researchers commonly draw on grounded theory and other methods simultaneously, often case study (Eisenhardt, 1989; Miles & Huberman, 1994; Yin, 2009). Eisenhardt (1989) uses cases constructed using case study methodology to build theory, and Miles and Huberman (1994) similarly present data analysis methods as tools in a toolbox and not a stone commandment. Miles and Huberman (1994) draw heavily from both Yin (2009) and Strauss and Corbin (2014) for analytic methods to narratively build cases and compare using matrix methods in approaches that could be interpreted either as
explanation-building and pattern matching (as in case study analysis) or selective coding (as in grounded theory analysis).

In my study, the overall goals and methods are consistent with the main tenants of grounded theory—as such, there are multiple sources of data, some of which are best constructed through case study methods. The following sections detail the data sources and the analysis methods for each.

Summary of Data Sources

Theoretical sampling guides the selection of data in this study. In particular, there are two branches of data used to draw comparisons and build theory: typical practice, and successful practice. The sources and their relation to the research questions are summarized in Figures 1.1-1.3.

Figure 1.1 Sources of data for research question one
Typical Propagation Practice

Developing an understanding of typical propagation practice of education developers is accomplished through identifying the practices of NSF principal investigators in an open response survey and focus group data from eight disciplinary groups of NSF program directors. Analysis of these sources leads to a characterization of what typical propagation practices look like within the context of NSF-funded education projects, allowing for comparative insights to be drawn from data on successful practice.
Successful Propagation Practice

Successful innovations across STEM disciplines are identified by a survey of experts and review of the literature, then analyzed as a set using publically-available data such as funding information and publications. This analysis provides a broad perspective of the types of innovations that are well-propagated and their funding characteristics.

From this set, three innovations are chosen for detailed case study, using interviews with the project teams and document and artifacts such as publications, grant proposals, online videos, and internal working papers. The cases are the PhET Interactive Simulations (Perkins et al., 2006; Wieman, Adams, Loeblein, & Perkins, 2010), Peer Instruction (Mazur, 1996), and Peer-Led Team Learning (Gosser et al., 2001). They represent different types of change, which the literature suggests is important to choosing propagation strategies. In rough terms, the PhET Interactive Simulations are much “simpler” to implement in the classroom than Peer Instruction, which is “simpler” to implement than Peer-Led Team Learning. This theoretical sampling helps build a model applicable to various types of innovations.

Finally, to fill in remaining questions, interviews with additional project team leaders from the list of well-propagated projects will target specific aspects of the model.

Data Collection and Analysis Methods

Each data source is analyzed continuously as data comes in, with findings from that analysis contributing to the overall model and refinement of future data collection (Corbin & Strauss, 2014; Miles & Huberman, 1994). Data analysis for the components of the study could be different depending on the source. The methods of data collection and analysis are summarized in Table 1.1.
### Table 1.1 Summary of data sources and data collection methods used in the study

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Data Collection Method</th>
<th>Data Analysis Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSF Program Directors</td>
<td>Focus group data with program directors in the Transforming Undergraduate Education in STEM (TUES) program. The project team held two-hour long meetings with each of the eight disciplinary groups of program directors (biology, chemistry, computer science, engineering, geoscience, math, physics, and interdisciplinary), facilitating discussion on their views on propagation. Detailed notes of the meetings were taken.</td>
<td>The detailed notes from the focus group meetings were analyzed by discipline, coding for themes. These themes were compared across disciplines; themes expressed by more than half were synthesized using language as close to that of the program directors as possible. These themes were sent to the program directors for member checking. They believed the document summarized their views.</td>
</tr>
<tr>
<td>NSF Principal Investigators</td>
<td>Open response survey data from 1285 recipients of NSF awards within the Course Curriculum and Laboratory Improvement (CCLI) program regarding dissemination methods and views (survey administered by Tront et al., 2011)</td>
<td>Coded the responses for dissemination activities and beliefs.</td>
</tr>
<tr>
<td>Experts in STEM education</td>
<td>Experts were identified by authorship on national reports, leadership in professional societies, and professional network suggestions. Experts responded to an email survey asking them what they believed to be well-propagated educational innovations in their discipline.</td>
<td>The list of innovations was checked for evidence of propagation using set criteria. The edited list was sent back to the experts for member checking, leading to additions and deletions. The list was shown to additional experts at a TUES PI meeting, where more suggestions were collected.</td>
</tr>
</tbody>
</table>

*This document served as a starting point in the model.*

*This was compared with the views of the program directors to develop an initial model.*

*This list will be used to construct an understanding of successful practice.*
<table>
<thead>
<tr>
<th>Data Source</th>
<th>Data Collection Method</th>
<th>Data Analysis Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Well-Propagated Innovations in STEM</td>
<td>Publications and website data were used to develop descriptions of each innovation. The descriptions were sent to the original developers of the innovation for checking, when possible. Publically available funding data was collected from project websites and funding databases.</td>
<td>The innovations on the list were categorized using an emergent coding scheme to capture the type of innovation. Ran descriptive statistics for the funding information.</td>
</tr>
<tr>
<td>Peer-Led Team Learning</td>
<td>Publications, guidebook, interviews with two project team members and a published book about the dissemination and institutionalization of Peer-Led Team Learning.</td>
<td>The funding information and types of projects that were well-propagated led to implications for the model.</td>
</tr>
<tr>
<td>PhET Interactive Simulations</td>
<td>Publications, website data, working internal papers, interviews with four project team members</td>
<td>Interviews were coded for actions undertaken by the project team. Document analysis of the publications and guidebook led to a narrative description of the project’s history.</td>
</tr>
<tr>
<td>Peer Instruction</td>
<td>Publications, website data, published book, book chapters, presentations, online videos, interviews with four project team members</td>
<td>Actions from this project team were compared with the emerging model from the program directors and principal investigators. Details from this case made the model more concrete.</td>
</tr>
</tbody>
</table>

Codes were added and refined to capture additional salient points from this case. Categories to describe groups of codes were developed.

Documents were used to construct a narrative and compare with interview claims. Interviews were coded with the same codebook as the prior study.

Documents were used to construct a narrative. Interviews were coded with the same codebook from before.
Table 1.1—Continued

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Data Collection Method</th>
<th>Data Analysis Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developers of additional well-propagated innovations</td>
<td>Interview data with lead developers of innovations, documents (project histories, relevant publications)</td>
<td>Codes were added and additional categories established. These led to knowledge propositions. Interviews will be coded with the same categories as before, checking against the propositions. Additional open codes in specific categories may be introduced if needed. This will allow for testing of aspects of the theory and filling in less-understood categories.</td>
</tr>
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</table>

Trustworthiness

Situating the Researcher

In a grounded theory study, the researcher needs to be open to the findings that the data shows, and not impose preconceptions onto the data. Therefore, description of possible preconceptions is warranted. One aspect of my background is especially relevant here: pre-existing knowledge of the literature in this area. The line between a healthy theoretical sensitivity to uncover potential findings and knowing too much is vague, but this study began prior to my having extensive knowledge of the literature, and my development as a researcher in this area (and thus reader of the literature) has been parallel to this study. As some grounded theory experts have noted, the very design of a PhD program runs contrary to an ideal grounded theory study in that the student must complete a literature review early in the program (Gibson & Hartman, 2014). Knowledge of major themes in the literature can lead one to pick out those themes from the data when perhaps they are not there. Analysis guides future data collection, so there is potential for a feedback loop of biased findings leading to biased sampling and more biased findings. While some grounded theorists might say reading anything at all is too much
foreknowledge, I believe some knowledge is necessary to make connections during analysis that might otherwise be missed. While enhanced theoretical sensitivity leads to those connections, it also does necessitate strategies to ensure validity, as described below.

Validity Measures

Qualitative work, in which the researcher is the instrument of data collection and analysis, necessitates checks for whether the conclusions are valid (Creswell, 2007; Lincoln & Guba, 1985; Marshall & Rossman, 2011). Lincoln and Guba (1985) describe four aspects of trustworthiness in a qualitative study: credibility, transferability, dependability, and confirmability. Credibility, or whether the study is believable within the context of its setting, can be established through setting defined boundaries around the study and member checking, in which the researcher provides the participants with the findings for feedback (Creswell, 2007; Marshall & Rossman, 2011). Here, this study draws boundaries by looking at specific innovations (as opposed to large movements like “active learning”) in higher STEM education (instead of including other fields and other education levels). Member checking through giving the participants summaries of the results and opportunity to review articles can be done in this study. Transferability, or the extent to which the findings are generalizable, can similarly be addressed through clear delineation of boundaries, and through the use of triangulation (Creswell, 2007; Marshall & Rossman, 2011). In this study, multiple sources of data are used—multiple cases, informants, and types of data such as interview and documents. Dependability is the extent to which the study is reliable, or repeatable given the same methods used by a different researcher. The results of this study could very well be different if conducted by another researcher given the many decision points made in developing theory and choices of data to pursue. However, frequent checks of assumptions with other researchers within the overall project to which this study is related, and the use of negative case analysis, or following up on points that do not exactly fit the working theory, provide a measure of internal reliability (Creswell, 2007). Finally, confirmability, or whether the results of the study make sense to other researchers, can be addressed through clear outlining of methods (Marshall & Rossman, 2011).
Chapter I Conclusion

The goal of this dissertation project is to address a critical problem in STEM education, promoting the adoption of innovations to improve teaching. The following chapters are in the form of three articles describing the phases of the project: characterizing well-propagated educational innovations in STEM, developing an initial model for successful propagation, and expanding on that model with more detail through additional interviews. The three articles will contribute to the literature on change in STEM education by providing a detailed model of project activities successfully-propagated innovations conducted to become widespread.
CHAPTER II

CHARACTERISTICS OF WELL-PROPAGATED TEACHING INNOVATIONS IN UNDERGRADUATE STEM

Abstract

Background

The undergraduate science, technology, engineering, and mathematics (STEM) education community has developed a large number of innovative teaching strategies and materials, but the majority of these go unused by instructors. To help understand how to improve adoption of evidence-based education innovations, this study focuses on innovations that have become widely used in college-level STEM instruction. Innovations were identified via a questionnaire emailed to experts in STEM instruction. Descriptions of identified innovations were validated by preparing brief descriptions of each innovation and sending them to the original developers, when applicable, for feedback, and searching relevant literature. Publicly available funding data was collected for each innovation. STEM disciplines surveyed include biology, chemistry, computer science, engineering, geoscience, mathematics, and physics.

Results

The 43 innovations identified were categorized based on two criteria: level of specificity (general, recognizable, branded) and type of change (pedagogical, content, both, neither). The 21 branded innovations were analyzed in more detail. The majority (14/21) require relatively modest changes in pedagogy and no changes in content. In addition, nearly all have received at least 3 million dollars in external funding over at least 10 years.

Conclusions

This paper presents the full list of instructional innovations produced, which can be used by educational innovation developers to understand how their ideas fit within the broader landscape and to identify innovations in one discipline that may have promise for transfer. The
findings regarding funding of the branded innovations have important implications for both educational innovation developers and funding agencies. In particular, the study indicates that a long-term mindset and access to long-term funding are vital for broad adoption of new teaching innovations.

Background

Within science, technology, engineering, and mathematics (STEM) disciplines, significant education research has focused on developing teaching innovations and evaluating their efficacy (National Research Council, 2012). This research has produced many new instructional strategies and teaching materials that have been shown to improve a variety of student-learning outcomes. However, most of these strategies are not widely used by STEM instructors (Austin 2011, Seymour, 2001, Fairweather 2008).

In contrast, there are some innovative teaching strategies that have become well known and widely used in STEM education. To begin to understand why some gain traction while others do not, we ask: are there factors and/or features common to instructional strategies that are widely used? If so, what are implications for developers of educational innovations? There have been many calls for reform in STEM education at the college level (Brewer & Smith, 2009; The White House, 2010) and, as noted above, many innovative teaching strategies have been developed and their efficacy well supported. The limited use of these strategies suggests that we lack a coherent framework for implementing widespread reform in college STEM teaching. This has been an active research area in recent years (D’Avanzo, 2013; Gannaway et al., 2011; Kezar, 2011; Litzinger et al., 2011; McKenna, Froyd, & Litzinger, 2014).

Most of the work in this area is focused on understanding why current practices typically fail. Here, we take the opposite approach and seek to build knowledge by studying the few educational innovations that have made it to significant levels of use.

There are several bodies of prior work that have influenced our conceptualization of this project and the results presented in this paper. An important way that researchers in many fields think about the spread of innovations is Rogers’ (2003) diffusion of innovations model. For example, this model has been used to examine awareness and implementation of innovations in physics and engineering education (Borrego et al. 2010; Henderson et al. 2012). While diffusion of innovations provides a useful way to conceptualize how and why innovations spread, it is not
sufficiently detailed for creating a dissemination plan. Several research groups have seen the need for a more detailed framework of dissemination of education innovations. In Australia, a detailed dissemination framework was evaluated for effectiveness among grant recipients, but the framework was found to be insufficient to promote understanding of dissemination planning (Gannaway et al. 2011). Developers used the language the framework provided but not its emphasis on planning, leading to revisions of the framework. Other researchers have conducted literature reviews and studies with grant recipients to explore what leads to successful dissemination (Bourrie et al. 2014; Hazen et al. 2012). These studies find that the interplay between factors such as the innovation itself and potential adopters is complex, and confirm that the process is consistent with Rogers’ (2003) ideas. For example, Bourrie et al. (2014), in a Delphi study of NSF grant recipients, found multiple factors lead to an innovation becoming successful, with the main factor being relative advantage. What are still needed are specific factors that can inform practice from the context of STEM education innovations.

To help identify these factors, we have identified a set of educational innovations that are well known and widely used along with basic information such as how long they have existed and been funded. We refer to these innovations as well-propagated instructional strategies and materials (WePISMs). A small number of these WePISMs have been identified and examined in depth to understand practices and processes that led to their widespread adoption (Khatri et al., 2016; Khatri, Henderson, Cole, & Froyd, 2014, 2015). The focus of this paper is to analyze the larger set.

Methods

This study was motivated by a desire to understand the current landscape of well-known and widely used undergraduate teaching innovations within STEM. We used qualitative methods suitable to develop an emergent understanding of this previously unknown situation (Creswell 2007). This study was carried out in several stages: initial data collection, validation of the results through additional data collection, and analysis using a new categorization scheme (Table 2.1).
### Table 2.1 Overview of the three study phases

<table>
<thead>
<tr>
<th>Initial Data Collection</th>
<th>Validation of Results</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Email survey of experts (N = 39 responses)</td>
<td>➢ Member check with initial N = 39 experts • Feedback from workshop with N = 70 participants</td>
<td>➢ Development of WePISM categories (degree of definition, type of change)</td>
</tr>
<tr>
<td>➢ Literature, public funding information, project website, digital libraries, (e.g. SERC, ComPADRE) used to construct understanding of each WePISM</td>
<td>➢ Use criteria to determine if the items on the list were appropriate and well-propagated</td>
<td>➢ Application of categories</td>
</tr>
<tr>
<td>➢ Member check with initial N = 39 experts • Feedback from workshop with N = 70 participants</td>
<td>➢ Application of categories</td>
<td>➢ Collection and analysis of funding and length of use data for branded WePISMs</td>
</tr>
</tbody>
</table>

### Initial Data Collection

An important goal of this study was to identify WePISMs. We began by surveying (via email) experts in research-based undergraduate teaching in the seven disciplines studied (biology, chemistry, computer science, engineering, geoscience, mathematics, physics). We identified experts through membership on national committees (e.g., National Research Council Discipline-Based Education Research (NRC DBER) committee), professional society leadership, and our professional networks of individuals who serve as journal editors and opinion leaders. We began with a list of at least ten experts from each discipline (except for computer science where we identified nine, see Table 2.2). After contacting these initial experts, if the minimum of five responses was not achieved, we asked the experts who did respond within their discipline to recommend additional experts we could contact.
Table 2.2 Number of experts contacted in each discipline

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Number of experts contacted</th>
<th>Number of responses (total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Chemistry</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Computer Science</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Engineering</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Geoscience</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Mathematics</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>Physics</td>
<td>12</td>
<td>7</td>
</tr>
</tbody>
</table>

Each expert was sent an email that briefly introduced the project and asked the expert to respond to the following prompt:

Please respond to this email and identify the five or so ‘new’ learning materials or teaching strategies that you feel have been most successfully propagated in undergraduate [DISCIPLINE]. It will be very helpful if you could also include a short explanation of why each was chosen.

In order to increase the response rate, we sent up to two reminder emails to non-responders. In these follow-ups, we also made a point to mention the names of team members who might be familiar to survey recipients (e.g., mentioning the name of our chemistry team member when emailing the chemistry experts). Most experts responded via email, while others (two) preferred to set up a phone call. Phone calls were not recorded, although the innovations named and the basic rationale for including them were written down during the phone call. A minimum of five responses was sought in each discipline. If we did not get five responses in a discipline with the initially identified experts, we contacted additional experts to achieve the minimum.

Validation of the List of WePISMS

All suggested innovations were included in the list, which was validated in several steps: applying inclusion criteria (discussed below), member checking with the expert responders, and presenting the list for feedback from 70 additional education researchers in various STEM disciplines. To help determine the extent to which each of the innovations on the list was widely
propagated, we used Google Scholar to identify publications about each of the innovations. In addition to the expert recommendations and literature search, we held focus group discussions with National Science Foundation (NSF) Transforming Undergraduate Education in STEM (TUES) program directors (Khatri et al., 2013). The primary motive behind the focus groups was to understand program director views of propagating educational innovations in general terms, but they frequently employed example innovations from their disciplines, and discussion of those innovations was considered additional evidence of propagation while checking the list. With this information, the list was winnowed using the following inclusion criteria for being counted as a well-propagated educational innovation:

1. Used primarily in college settings. Some items suggested by the experts were designed for and primarily used in K-12 settings, which was not our area of focus.

2. Used primarily as a teaching tool. Some items suggested by the experts, such as concept inventories, are more frequently used for research and evaluation rather than for instruction. Although we realize that there is no clear line, we nonetheless decided to exclude items used primarily for research and evaluation from our list.

3. All items on the list, in addition to meeting the first two criteria, also required evidence of significant use by others. We operationally define “significant use” as being used by at least 100 institutions or being highly visible in the field. We collected the following sources for evidence of significant use: (i) being mentioned by significant reports or papers authored by non-developers, such as being mentioned in the NRC DBER report (National Research Council, 2012), (ii) literature written by innovation adopters who reported their experience in an education journal, (iii) being included in a well-attended workshop program, such as the Science Education Resource Center (SERC) On the Cutting Edge workshops (Gosselin, Manduca, Bralower, & Mogk, 2013), (iv) existence of a conference devoted solely to the innovation (e.g., (Dreyfuss, 2013)), (v) frequency of mentions by experts, and (vi) Internet searches for examples of implementations and/or data provided by the innovation developers. Occurrences in more than one of these sources were required in order for an innovation to be judged as being significantly used.
As an example for applying the criteria, Workshop Physics\(^1\) is (1) used in college settings and (2) used primarily as a teaching tool. When we apply (3) (significant use), however, it is not clear that Workshop Physics has ever been particularly highly used. But, it is clear that Workshop Physics is highly visible in the field and has contributed significantly to advances in how the physics community thinks about undergraduate instruction (Laws, 1991). Therefore, Workshop Physics is included on the list.

Applying these criteria yielded an edited version two of the list, which was sent back to the participants for member checking. A participant received a list containing only innovations from version two specific to their discipline. Participants often disagreed on items in the second list and suggested a few more that could possibly be included, giving opinions or evidence as to why. We examined additional suggestions and applied the same criteria to determine if they should be added to the WePISM list. In addition, we used participant responses critiquing the spread of some innovations to remove some from the list, yielding version three of the list.

We used several available opportunities to validate version three of the list. The largest opportunity was at the TUES principal investigator (PI) meeting in January 2013. The list was presented both in a workshop with 70 participants and in a poster session (Henderson & Cole, 2013). These meeting participants had all received NSF education grant funding and were knowledgeable in their discipline. We received feedback on the innovations included and suggestions for additional innovations to include. We also sought and received feedback on the list from our project advisory board. After carefully considering this feedback and the other available evidence, in Spring 2015, we considered the list to be finalized. The final list contained 43 innovations.

Analysis of the WePISMs

Once the 43 WePISMs were identified additional analysis was needed to develop a better understanding of them. This involved collecting additional information about each WePISM and developing a categorization scheme to highlight important WePISM characteristics. The first step in the analysis process was gathering additional data to develop a preliminary understanding of each of the innovations, many of which were outside of our fields. With the aid of digital

---

1 Workshop Physics: Instructional format in which traditional lectures and weekly laboratory sessions in a calculus-based introductory physics are replaced with inquiry-oriented activities and occasional demonstrations.
libraries, literature, project abstracts, and project websites, we wrote a brief (~100 words) description of each. These were sent to the developers of the WePISMs for review and approval when a project leader for the innovation could be identified and contacted.

Categorization Scheme for Educational Innovations

We searched the literature for an existing categorization scheme for educational innovations to begin characterizing the WePISMs. While we found some published schemes, none of these were suitable for our purposes. The most promising of these was developed by Ruiz-Primo et al. (2011), who identified four characteristics of educational innovations: conceptually oriented tasks, collaborative learning activities, technology, and inquiry-based projects. They found many of the 868 papers they analyzed combined one or more of these types, citing Peer Instruction\(^2\) (Mazur, 1999) as an example that combines technology, collaborative learning, and conceptual tasks. We found, though, that categorizing our list in terms of these characteristics was not always possible and did not lead to meaningful groupings. For example, a major problem in using this scheme was that it uncomfortably put all the “technology” things together—even though BlueJ\(^3\) (Kölling, Quig, Patterson, & Rosenberg, 2003), PhET Simulations\(^4\) (Wieman, Adams, & Perkins, 2008), and online homework are only similar in that they are all accessed on a computer. Their differences, intention and use of these innovations, however, outweigh this similarity.

Therefore, we needed to develop a new categorization scheme that would help us better understand this set of instructional strategies with respect to their successful propagation. A categorization scheme should be both replicable (different researchers can classify items the same way into the same categories) and theoretically meaningful (creating a basis for new insights). After many iterations and much discussion, we arrived at the categorization scheme presented in Table 2.3, which is based on whether use of the innovation requires a change in

\(^2\) Peer Instruction: Lecture-based strategy in which the instructor intersperses brief presentations with conceptual questions (i.e., ConcepTests), and allows students to respond. After responding, students discuss their answers in pairs and then respond again.

\(^3\) BlueJ: Intro programming environment based in objects-first teaching, intended for introductory Java instruction.

\(^4\) PhET Interactive Simulations: Over 125 free online and downloadable simulations, targeting a large number of physics and astronomy concepts (with more recently added simulations in chemistry, geoscience, biology, and mathematics).
content, pedagogy, neither, or both. Each innovation on the list was coded separately by all six authors and discussed to come to agreement on its categorization.

Table 2.3 The authors’ categorization scheme of types of educational innovations

<table>
<thead>
<tr>
<th>Change in content</th>
<th>3. Implementation requires use of new course content (e.g. objects-first learning)</th>
<th>4. Implementation requires use of new/revised course content and pedagogy (e.g. Alice, Geogebra)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change in content</td>
<td>1. Implementation does not require change in pedagogy or course content (e.g. online homework)</td>
<td>2. Implementation requires use of new course pedagogy (e.g. Peer Instruction)</td>
</tr>
</tbody>
</table>

No change in pedagogy  Change in pedagogy

This categorization scheme is discussed in more detail elsewhere (Stanford et al., 2016). In addition to placing each of the 43 innovations into one of the four categories in Table 2.3, we needed a second categorization scheme to further differentiate the innovations. Some innovations in the final list include large movements and big ideas in STEM education (e.g., use of metacognition) or large umbrella terms for many other innovations (e.g., active learning), while others were specific and their proper name well recognized (e.g., the PhET Interactive Simulations). A categorization scheme was needed to differentiate the innovations along this as yet undefined dimension. We used the following scheme: general (innovation is an idea with various types of implementation), recognizable (innovation is clear but without central leadership), and branded (innovation is clear and has central leadership) (Table 2.4). This second scheme proved useful when the authors studied factors that influenced propagation of the innovations (see following section).
Using the two categorization schemes, the six authors classified the list of 43 WePISMs. The team then discussed their individual ratings and disagreements were resolved to reach consensus in coding.

Data Collection of Branded WePISMs

We sought to identify the number of funding sources, years funded, and total amount of funding for each WePISM. We found that this information could be identified for most of the branded innovations, but not the general or recognizable innovations. Thus, this part of the study was conducted only with the 21 branded innovations. We identified the PIs of the branded innovations through project websites and literature and used search engines for the funding agencies and the websites for the innovations (when appropriate) to gather funding information. We note that not all funding agencies make their funding amounts public. As a result, there may be funding for many innovations beyond what was listed by project websites. The amounts presented in the results section are likely to be a low estimate for some innovations. We sent the ~100-word project description to the original project PI (or, if unavailable, a prominent champion of the innovation) to allow them to check our understanding of the essence of their innovation (example descriptions in Table 2.5). We sent them the entire list of branded innovations in order to place their innovation into context, as we anticipated that without the

<table>
<thead>
<tr>
<th>Specificity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>A movement or broad theoretical term in education literature with many possible implementations (e.g. metacognition, active learning)</td>
</tr>
<tr>
<td>Recognizable</td>
<td>The innovation has a name which is associated with a set of teaching practices, but has no central leadership (e.g. flipped classroom, think-pair-share)</td>
</tr>
<tr>
<td>Branded</td>
<td>The innovation name is associated with a set of teaching practices and has central leadership (e.g. PhET Simulations, Peer Instruction)</td>
</tr>
</tbody>
</table>
context of the other short descriptions, they would say that our description was too short. In some cases, they wrote entirely new descriptions, and others gave a simple “Okay” to what we sent.

Table 2.5 Example descriptions from branded innovations list

<table>
<thead>
<tr>
<th>Innovation name</th>
<th>Description</th>
<th>Disciplines mentioned</th>
</tr>
</thead>
</table>
| CATME Team Tools                 | Online tool that allows instructors to form groups of students using default or instructor-defined data surveyed from the students.  
• Instructors can also collect self- and peer-evaluation data on team-member effectiveness according to a scientific model.  
• The system provides diagnostic information to the instructor about teams that may require intervention.  
• Developed by M. Ohland and M. Laughry.                                                                 | Computer Science       |
| Learning Assistants              | Undergraduate students are hired to facilitate small-group interaction in large-enrollment undergraduate courses.  
• This can occur either during whole-class sessions or in recitation sessions.  
• Learning assistants are given training in leading group discussion and meet regularly with the course instructor.  
• Originally developed by V. Otero.                                                                                                   | Physics                |
| Process Oriented Guided Inquiry Learning | Instructional format where students work in self-managed teams on inquiry-type activities.  
• Activities are written in a specific manner, and the instructor can write their own if they desire and submit it for review.  
• Instructors using POGIL do not use a traditional lecture format but instead provide guidance and facilitate student activities.  
• POGIL has been adapted to work within a variety of class sizes and physical structures.  
• Developed by R. Moog et al.                                                                                                           | Chemistry              |

Results

We present the results of this study in two parts: 1) the final list of all 43 WePISMs, and 2) a more detailed analysis of the 21 branded innovations for which there was additional publically available data. Attributes of WePISMs discussed are based upon the email questions
and member checking results. For example, identification of disciplines mentioning an innovation was only based on the email surveys of experts, not additional searches of the literature, although examples may be found in literature of WePISMs crossing over into other disciplines. We took this approach because the items on the list were validated with external sources. While use by other disciplines could be evidence of propagation, it does not imply widespread use in the other discipline. External information (literature, digital libraries) was used to inform coding decisions regarding project type and level of specificity.

Characteristics of the WePISMs Overall

The number of WePISMs identified in each discipline ranged from 6 to 16 (Figure 2.1). Geoscience and physics had more, while chemistry, engineering, and computer science had fewer WePISMs. In addition to potential bias from the number of experts initially contacted in each discipline, disciplinary differences in the number of WePISMs were likely influenced by some extraneous factors. For example, the well-documented history of physics education research (Cummings, 2011) and the centralized resources in geoscience (SERC) may have contributed to listing innovations that we were able to confirm were indeed well-propagated.

![Discipline use of innovations](image)

Figure 2.1 Number of WePISMs reported by experts across disciplines
Further examining the breakdown of the level of specificity of WePISMs, there are notable differences in several disciplines (Figure 2.1). Most share an even mix of general, recognizable, and branded innovations. Biology and geoscience mentioned the use of recognizable WePISMs most frequently, but all disciplines mentioned using some of these innovations. Physics experts mentioned using the most branded innovations, followed by math. Engineering reported using no branded innovations. A chi square test (comparing projected and actual counts) showed significant differences between physics, engineering, and geoscience in use of branded, recognizable, and general innovations (Greenwood & Nikulin, 1996). Physics uses more branded innovations, geoscience uses more recognizable, and engineering uses more general innovations.

![Innovation type and level of specificity](image)

**Figure 2.2 Type and level of specificity of WePISMs**

We also examined WePISMs by categorization of innovations, as shown in Figure 2.2, a breakdown of the WePISMs (N=43) by the categorization scheme described in Table 2.3. The columns are further broken into level of specificity (Table 2.4). Most WePISMs invoke only pedagogical changes (60%). This is followed by innovations that do not require a change in pedagogy or content (28%) and innovations that require a change in both pedagogy and content.
(9%). There was only one innovation reported which required a change in content only (objects-first learning in computer science).

Branded WePISMs

Using publically available data about funding, we can offer more details about the branded WePISMs. We discuss the amount of time branded WePISMs were funded, the amount of funding, and the number of sources of funding. Figure 2.3 displays box-and-whisker plots showing number of years of funding and the amount of funding for the branded WePISMs. The median time was 15 years and the median amount was 3.1 million dollars. The boxes represent the second and third quartiles.

The branded innovations all received funding for a period of at least eight years, with most receiving continuous or nearly continuous funding for over ten years (Figure 2.3).
The amount of funding covers a wide range, with the lower end at a half million dollars and a median of 3.1 million dollars (Figure 2.3). It is important to note that these are low estimates since most innovations have some funding sources that do not disclose funding amounts. For example, unlike public funding agencies such as the National Science Foundation, companies and institutions backing an innovation often do not publicly report funding amounts. Figure 2.4 displays box and whisker plot showing the number of funding sources for the branded WePISMs. The median amount was 3. The boxes represent the second and third quartiles.

![Box and Whisker Plot](image)

Figure 2.4 Number of funding sources for WePISMs

Many of the innovations had more than one funding source (Figure 2.4). Most received funding from between two to five sources. Nearly all received funding from Federal sources (mainly the National Science Foundation). Additional funding sources were often the institution where the innovation was developed or private foundations and companies. Notably, computer program innovations such as the PhET Simulations, Geogebra\(^5\), and ALICE\(^6\) received funding from a large number of sources (20 or more).

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\(^5\) Geogebra: Interactive software that joins geometry with algebra and calculus: rather than just showing and manipulating shapes, shapes are linked with algebraic expressions and spreadsheets in different views.

\(^6\) Alice: Intro programming environment for object-oriented programming.
Discussion

Disciplinary Differences

Many of the WePISMs originating in physics are branded, in contrast to geoscience and engineering, which have more recognizable and general innovations. There are several possible reasons for this difference. Physics education research as a field is one of the older STEM education fields, and some of the well-propagated innovations are well-documented as part of the history of the field (Cummings, 2011; National Research Council, 2012). It could also be due to disciplinary differences. Engineering education encompasses many individual engineering disciplines (mechanical engineering, electrical engineering, civil engineering, etc.). Educational innovations adopted in these disciplines may be as different as the differences between physics and geosciences. Thus, engineering may rely on umbrella ideas more heavily than physics. Geoscience is more place-based, so instructional strategies for one setting may not transfer to others, but the overall template for a change might.

Content Innovations

In this study only one innovation focused on content change could be confirmed to be well-propagated (objects-first learning in computer science). Several more were suggested, such as the Matter and Interactions course and textbook (Chabay & Sherwood, 1999), but these candidates could not be verified as well-propagated based on the criteria and data available for this study. The focus on pedagogy may imply a lack of development of content innovations, or it may be that content innovations are not being propagated. Possible barriers to propagation of content-based innovations might include disciplinary norms and expectations of content coverage at the departmental and interdepartmental levels. It may be that content innovations require a large amount of cooperation between individuals and departments and thus are slow to be implemented, while innovations focused on pedagogy are more easily adopted within existing institutional structures. This is an area that requires more investigation. Although we think of pedagogy as being firmly entrenched in higher education our findings suggest that content may be even more so. If content-based innovations are, in fact, less likely to spread it is important for education researchers to ask themselves about the desirability of this state of affairs.
Funding Implications

The findings regarding funding of the branded innovations have implications for educational developers. First, based on this study, characteristics of innovations likely to be broadly adopted can be identified at the proposal review stage. This study has found that innovations requiring content changes are unlikely to propagate widely using existing strategies. Therefore, if the goal of a project is broad adoption, then projects expecting significant content change should either propose significantly different propagation strategies or not be undertaken. Second, branded, broadly-adopted innovations received significant funding over a minimum of eight years. For projects aiming for broad propagation and expecting pedagogical change, propagation plans should be developed with long-time horizons. Educational development projects may have goals other than broad adoption within a ten-year time horizon; for example, projects may be funded to stimulate consideration of a variety of very different content in some established courses. If this is the case, then goals for these projects should be clear to both developers and any organizations funding these projects.

These findings have implications for modifying existing funding structures. A typical grant for an education project lasts three or four years, so getting to the 8-10 years of funding that we found as a minimum for successful propagation means pursuing multiple grants. Developers often think that publishing and presenting results of the work at the end of a three-year grant will mean the innovation reaches others. However, the implication here is that in addition to having a good idea, developers need to be willing and able to spend a decade or more working on an innovation and pursuing funding opportunities in order to develop something that can be well-propagated. As a result, funding agencies may wish to consider extension funding mechanisms for educational innovations that have demonstrated progress on developing, implementing, and evaluating propagation plans during the initial three-to-four year grant period.

Future Research

While this study focused on the innovations that were well-propagated, another avenue for study is studying innovations that were funded but did not reach a level of significant use. One study has done something similar to this (Stanford et al., 2017) analyzing the propagation of a set of funded proposals, looking at outcomes several years later. A comparative analysis of
well-propagated and not-as-well-propagated funded innovations could further illuminate factors related to propagation.

Conclusions

The purpose of this article was to discuss the characteristics of instructional strategies and materials that have spread well within undergraduate STEM education, and consider some of the factors associated with their propagation. We refer to these strategies and materials as WePISMs and identified 43 WePISMs with multiple ones in each STEM discipline. Across all 43 WePISMs, most of the disciplines had similar mixes of general, recognizable, and branded innovations. However, engineering, geoscience, and physics were significantly different from each other: engineering had more general, geoscience more recognizable, and physics more branded innovations. Overall, WePISMs largely represent changes to pedagogy, not changes to content, and the branded WePISMs share significant levels of external funding (median $3.1M) over an extended period (median 15 years).

We hope these findings, and the new vocabulary introduced in this paper to discuss educational innovations, may help developers think more explicitly about the type of change they wish to create and a propagation plan to support their goals.
CHAPTER III

DESIGNING FOR SUSTAINED ADOPTION: A MODEL OF DEVELOPING EDUCATIONAL INNOVATIONS FOR SUCCESSFUL PROPAGATION

Abstract

[This paper is part of the Focused Collection on Preparing and Supporting University Physics Educators.] The physics education research community has produced a wealth of knowledge about effective teaching and learning of college level physics. Based on this knowledge, many research-proven instructional strategies and teaching materials have been developed and are currently available to instructors. Unfortunately, these intensive research and development activities have failed to influence the teaching practices of many physics instructors. This paper describes interim results of a larger study to develop a model of designing materials for successful propagation. The larger study includes three phases, the first two of which are reported here. The goal of the first phase was to characterize typical propagation practices of education developers, using data from a survey of 1284 National Science Foundation (NSF) principal investigators and focus group data from eight disciplinary groups of NSF program directors. The goal of the second phase was to develop an understanding of successful practice by studying three instructional strategies that have been well propagated. The result of the first two phases is a tentative model of designing for successful propagation, which will be further validated in the third phase through purposeful sampling of additional well-propagated instructional strategies along with typical education development projects. We found that interaction with potential adopters was one of the key missing ingredients in typical education development activities. Education developers often develop a polished product before getting feedback, rely on mass-market communication channels for dissemination, and do not plan for supporting adopters during implementation. The tentative model resulting from this study identifies three key propagation activities: interactive development, interactive dissemination, and support of adopters. Interactive development uses significant feedback from potential adopters to develop a strong product suitable for use in many settings. Interactive dissemination
uses personal interactions to reach and motivate potential users. Support of adopters is missing from typical propagation practice and is important to reduce the burden of implementation and increases the likelihood of successful adoption.

**Introduction**

Physics education research as a field has been highly prolific in developing new instructional strategies and teaching materials (Beichner, 2009; Cummings, 2011; National Research Council, 2012). Implementation of these strategies and materials has repeatedly been shown to result in significant positive impacts on students (Committee on Undergraduate Physics Education Research and Implementation, 2013).

The reality faced by physics education researchers, however, is that developing good materials and documenting their effectiveness is not sufficient to promote widespread adoption. New strategies and materials are often presented by the developers at conferences and published in academic journals (Tront et al., 2011). Research shows that while many instructors are aware of new teaching strategies and materials, the use of these strategies lags substantially behind awareness (Henderson & Dancy, 2009). Additionally, when instructors try a new strategy or material, they often discontinue use (Henderson, Dancy, et al., 2012) or make modifications to the original work that can potentially render the strategy ineffective (Henderson & Dancy, 2007).

The challenge faced by education researchers, then, is how to better propagate their new instructional strategies. In this paper we purposefully use the term “propagation” to draw attention to the difference between propagation and the more commonly used term “dissemination.” Propagation puts the focus on the users of a new instructional strategy. Propagation has occurred when others use the new instructional strategy or material. Propagation activities are the ways that developers (and others) seek to create propagation. Dissemination, on the other hand, puts the focus on the developer. Dissemination has occurred when the developer tells others about a new instructional strategy, often via one-way communication mechanisms (Henderson, Cole, et al., 2012). Telling people about new ideas (i.e., dissemination) is rarely sufficient to get others to use a new teaching strategy or material (Rogers, 2003). Thus, while dissemination is an important propagation activity, it is only one part of a successful propagation plan. In order to improve the situation, we need a better model of designing for successful propagation that can help education developers construct propagation plans that lead to sustained
adoption of education innovations. This paper describes the first two phases of a three-phase study to develop such a model.

Literature Review

Here we briefly summarize some of the key pieces of knowledge from the literature about effective development and dissemination. We will do this based on three recent syntheses that draw on a large number of primary sources. More specific connections between the results of this study and particular findings in the literature will be made when relevant in the results sections.

One piece of relevant literature situates this study in the wider landscape of research on change in higher education (Henderson et al., 2011). Henderson, Beach, and Finkelstein (2011) conducted a review of $N = 191$ journal articles regarding change strategies in higher education. They identified three communities of researchers interested in improving undergraduate science, technology, engineering, and mathematics (STEM) instruction: STEM education researchers, faculty development researchers, and higher education researchers. Each of these communities had a preferred change strategy, with STEM education researchers focusing on the development and dissemination of curricula and pedagogy. The research presented in this paper is situated within the “disseminating curricula and pedagogy” change strategy in which education researchers develop new teaching materials and then inform individual instructors about these new materials. While other change strategies are also relevant in STEM education, the development and dissemination strategy is the prevailing way of thinking about change in the STEM education research community and thus it is important to consider what successful practice looks like within this change strategy.

There have been two recent syntheses that focus on how to minimize the gap between research and practice (Fixsen et al., 2005; Hinton et al., 2011). Fixsen et al. (2005) reviewed $N = 743$ articles about program implementation outcomes in different fields (e.g., psychology, engineering, social services, and justice.) The review generated a model of stages of implementation for programs and highlights the importance of change agents understanding the context of local implementation and engaging in frequent communication between program leaders and on-site staff for better fidelity of implementation. This emphasis on the context of local implementation and communication between program leadership and others is echoed in Hinton et al. (2011). This guide for education researchers who want to disseminate their work
more effectively is based on a review of funded education development projects in Australia. It describes strategies researchers can use to communicate with potential adopters, and advises project teams to begin dissemination efforts at the beginning of their projects. Both sources are also concerned with the sustainability of new programs once funding for them is over. The agreed-upon points from these syntheses are threefold: (i) the context in which a new innovation is being implemented matters, (ii) communication between developers and potential adopters is necessary for implementation, and (iii) it is difficult to develop a product that results in sustained use after the funding period is over. These sources provide some useful elaboration of the barriers to successful propagation and point to some of the key features of the system that should be considered when thinking about propagation.

Research Design

While much is known about the process of adoption of innovations in general (Rogers, 2003) and common barriers to propagation (Fixsen et al., 2005; Hinton et al., 2011), less is understood about the practices of education developers that lead to sustained adoption of innovations within the specific context of funded projects in undergraduate STEM instruction. The goal of this work is to develop a better understanding of the practices that lead to successful adoption. The outcome of the work is a model (i.e., a “theory”) of designing for successful propagation within the context of higher STEM education.

Grounded theory guides the overall design of this multiphase study, visualized in Figure 3.1.
Figure 3.1 Overview of the larger study

Note: This paper describes phases 1 and 2, which have resulted in a tentative model of educational development for successful propagation.

In a grounded theory study, the researchers begin with the data (not theoretical suppositions) and the theory is developed to fit the data (Charmaz, 2006). Grounded theory studies typically begin with an open-ended research question (like our goal above) which can become more focused as the study progresses (Corbin & Strauss, 2014). While people often think about a grounded theory study as being built on approximately 20 interviews with individual informants, grounded theory studies can and frequently do have multiple sources of data beyond interviews (Suddaby, 2006).

The core ideas of grounded theory that we employ here are as follows:

- **Theoretical sampling.** This means targeting specific sources of data which will best address the research goal, rather than aiming for a generalizable sample (Charmaz, 2006)
- **The constant comparative method.** Using this method, new data are interpreted as they are collected. Interpretation of past data can change as new insights are reached (Creswell, 2007).
• Creative intuition. In a grounded theory study it is appropriate to not merely document codes but elevate those codes to theoretical constructs with the input of creative insight (Suddaby, 2006).

In keeping with the grounded theory approach, we build an emerging theory from the raw data in several steps, with the end result being knowledge propositions. Our design is similar to a study designed to identify reasons for the overrepresentation of minority students in special education programs in large school districts (Harry et al., 2005). This study consisted of three phases: (i) describing the overall program process with data from a district, (ii) purposefully identifying 12 schools within the district to describe their program referral process in a more specific context, and (iii) in-depth case studies of 12 students to understand issues that had arisen in the data. Their analysis began with open coding and led into the creation of interrelated categories, carried over throughout the phases. Our study is similar in the phases of data collection and the overarching analysis scheme across the phases.

Each phase of our overall study, illustrated in Figure 3.1, has a subgoal and involves gathering specific data to achieve that subgoal. The goal of the first phase was to develop an understanding of typical propagation practice of education developers. We used data from a survey of $N = 1284$ National Science Foundation (NSF) principal investigators (PIs) and focus group data from eight disciplinary groups of NSF program directors. The goal of the second phase was to develop an understanding of successful propagation practice through detailed study of three instructional strategies that have been well propagated: Peer-Led Team Learning (Gafney & Varma-Nelson, 2008), the PhET Interactive Simulations (Perkins et al., 2006), and Peer Instruction (Mazur, 1996). The third phase will further build upon the tentative model resulting from the first two phases using data from interviews with a purposeful sampling of PIs of additional successfully propagated instructional strategies, as well as interviews with PIs of typical education development projects at the conclusion of their funding period.

Similar to many qualitative research traditions, the goal of grounded theory is to systematically develop emergent ideas beginning with the raw data. We began data analysis with open coding. Codes were grouped under categories, and categories were explained with propositions (which could interrelate), and finally a model was developed to combine the propositions. The overall analysis plan is depicted in Figure 3.2 below. Our approach is to capture the actions and beliefs present in interview and document data, describe what is going on
through codes, organize those codes into descriptive categories, use propositions to interpret the
categories, and finally combine the propositions to create a model.

![Data → Codes → Categories → Propositions → Model]

Figure 3.2 Analysis plan to develop a model

A detailed description of the first two phases and their respective methods and results are
provided in the following sections.

Phase 1

We started our model development process by examining the current propagation
practices of education developers. This allows for comparison between typical and successful
practice, and it allows the final model to reflect the good parts (if any) that exist in current
practice. Data for phase 1 came from a web survey of 1284 NSF principal investigators (PIs) and
focus group interviews with 30 NSF program directors. These groups of key informants and
comparison between their responses allowed us to construct a baseline of typical propagation
practice in funded NSF projects.

Phase 1 Methodology

NSF Principal Investigators

One data source for phase 1 was a survey of \( N = 1284 \) NSF Course, Curriculum, and
Laboratory Improvement (CCLI) PIs. The survey aimed to capture the dissemination practices of
CCLI PIs and was developed and implemented by Tront and colleagues (Tront et al., 2011). The
survey was sent to \( N \sim 2400 \) CCLI award winners (the predecessor to the Transforming
Undergraduate Education in STEM, or TUES, program) and resulted in 1284 usable responses.
With permission, we analyzed responses to three questions from the survey that related to PI beliefs about propagation of educational innovations (Figure 3.3).

**Survey Question 7:**
7. Briefly describe what successful dissemination of your educational innovation means to you? (Please be as specific as possible, e.g., instead of ‘lots of users’, tell us how many users, i.e., 1 user or 1,000 users.)

**Survey Questions 14 and 15:**
14. Please rate the importance of the following possible barriers in disseminating your educational innovation (Likert scale from ‘not at all important’ to ‘extremely important’).
   - Dissemination of my innovation is not a priority to me
   - Lack of financial resources to support dissemination activities
   - Don’t know where or how to disseminate
   - Lack of peer reviewed journals focusing on educational innovation in my field
   - Technology changed so rapidly that educational innovation became out of date
   - Lack of peer reviewed conferences focusing on educational innovation in my field
   - Dissemination activities are not valued by my institution
   - Other (please specify)

15. Please make any comments you have about this survey or about dissemination of your educational innovation.

*Figure 3.3 Survey questions analyzed (adapted from Khatri et al. 2013)*

Analysis of questions 7, 14, and 15 began with a round of open coding to capture the essence of the responses, followed by several iterations of coding to produce categories with more descriptive subcodes. These categories were used to synthesize propositions. Many PIs used the space in “other, please specify” in question 14 and used 15 to provide further information on barriers, so the open ended responses from questions 14 and 15 were combined in the analysis. Note that the Likert scale options of question 14 provided ideas on barriers to the PIs, and they used the “other” space to go on further beyond the listed barriers.
NSF Program Directors

The second data source used in phase 1 was informal focus group conversations with the NSF TUES program directors (Khatri et al., 2013). The 8 focus groups with 30 total program directors (all approximately 2 h long) were conducted by us and took place at NSF. Each group consisted of program directors who worked in a particular TUES discipline (biology, chemistry, computer science, engineering, geoscience, interdisciplinary, physics, and mathematics). We asked the program directors for their perspectives on what leads to successful propagation of TUES projects and what problems occur during propagation of TUES projects. We took detailed notes of the discussions. In the analysis we developed codes relating to propagation for each disciplinary group. Similar codes expressed by the program director groups were combined into categories and written in language that best represented the ideas expressed by the groups. These emerging categories were also revised through discussions within the research team and compiled in a two-page summary document. Program directors were given the opportunity to comment on this summary document. These categories contributed, like the categories from the PI survey analysis, to propositions.

Phase 1 Results

Results from NSF Principal Investigators

i. What does successful dissemination mean to PIs?

The analysis of question 7, “What does successful dissemination mean to you?” allowed us to understand how PIs view the propagation process. PIs largely responded to question 7 in terms of providing a dissemination activity that they plan to carry out, the results of using such an activity (in terms of numbers as the question suggested), or they provided both an activity and how many users they would ideally reach. The percentage breakdown and example responses are given in Table 3.1.
Table 3.1 Example PI responses to question 7 and coding (adapted from Khatri et al. 2013)

<table>
<thead>
<tr>
<th>Primary Category</th>
<th>Example PI Response</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissemination activity</td>
<td>“Presentations at regional and national conferences, publications in widely distributed journals (focused both at practitioners and researchers), online or hardcopy publication of curriculum materials”</td>
<td>20</td>
</tr>
<tr>
<td>Result of using activity (adoption, numbers of users)</td>
<td>“25 other college faculty would use one of the instructional modules developed for this course.”</td>
<td>55</td>
</tr>
<tr>
<td>Both an activity and the results</td>
<td>“Publication of products - commercialization Use by more than one class in one institution Obviously this depends on the project.”</td>
<td>11</td>
</tr>
<tr>
<td>Other (definitions of dissemination)</td>
<td>“The innovation is shared with a significant percentage of those educators who are interested in the particular field or area.”</td>
<td>12</td>
</tr>
<tr>
<td>They did not know or haven’t disseminated</td>
<td>“We have not disseminated our material yet, we are only at the developmental stage.”</td>
<td>2</td>
</tr>
</tbody>
</table>

We note that the phrasing of question 7 likely primed respondents in terms of the number of users, which is why 55% provided a number of users. Each category is discussed below.

**Dissemination activities**

Dissemination activities mentioned by PIs who gave them as part of their response were categorized using an emergent coding scheme. Six main codes emerged: publications (28%), presentations (20%), share with colleagues (12%), workshops (17%), website (10%), and textbooks (10%). Among the 241 PIs who mentioned a dissemination strategy, only 7 (2.9%) mentioned a dissemination activity that did not fit into one of the six previously mentioned. These methods included a white paper, producing a DVD, printing a brochure, mentoring students to pass on their work, and directly distributing a report to thousands of departments in the country and to policy makers. The emphasis on publications and conferences is also seen the Tront et al. (2011) analysis of the survey.
Result of using the dissemination activities

PIs who mentioned adoption (often in terms of numbers) as successful dissemination targeted two groups: external and internal adopters. Across disciplines, 71% of PIs indicated that it would be a success if others used the innovation outside of their home institution. Another 20% would consider dissemination to be a success if they influenced faculty or administration at their own institution. The remaining PIs (8.5%) in this category thought of adoption as stages involving both internal and external adoption, first at their home institution and then beyond.

Other definitions of dissemination

In spite of the priming from the question to give a number of adopters, many respondents provided “other” definitions of dissemination (12% as listed in Table 3.1, or 150 respondents total). These definitions mainly fell into three categories: (i) informing other colleagues or instructors that the innovation exists, (ii) to bring about change in their discipline or science education as a whole, and (iii) to make the innovation freely available to other instructors. Some respondents who provided “other” definitions (6%) made a distinction between dissemination and adoption, seeing them as different terms. This is consistent with our definition of propagation as discussed earlier. Overall, however, the survey wording conflated the ideas of dissemination and adoption and most PIs went along with that conflation.

“Have not disseminated yet.”

This is a small category but we draw attention to it (2% of responses in Table 3.1). PIs with this response often said that they were at the beginning of their project and had not yet began to think about dissemination.

ii. What barriers to dissemination are PIs concerned about?

In our analysis of questions 14 or 5 about the barriers PIs experienced, PIs overwhelmingly cited lack of some kind of resource, most commonly time, as a barrier to disseminating their work. Other resources they lacked were funding and personnel. There was also demand from PIs for more resources from the NSF (besides funding), such as a special
conference for the dissemination of TUES projects, a marketing team for TUES projects, and help assessing the innovations for efficacy.

Results from NSF Program Directors

Three categories were developed from the program director focus groups: propagation activities used by PIs that are not effective, propagation activities used by PIs that are effective, and barriers to propagation. Each focus group had both discipline-specific and general codes within each of the three categories. The discipline-specific codes largely focused on disciplinary barriers, such as the lack of centralized professional societies in biology and for interdisciplinary projects, and the size of engineering as a discipline. Here we focus on the three categories and the general codes within each category.

i. Propagation activities that are not effective

Program directors felt that the typical dissemination methods used by PIs, e.g., journal articles and conference presentations, are not resulting in propagation. This was mainly because these mechanisms did not reach the desired audiences. For example,

- Computer science, engineering, and interdisciplinary specifically mentioned that publications are not useful.
- Chemistry and geoscience specifically mentioned conferences as not useful: chemistry because the education and science parts of their conferences are not well integrated, and geoscience because they do not engage new educators besides “the choir” who come to all the conferences.

ii. Propagation activities that are effective

Program directors identified several characteristics of projects that they felt increase the chances of successful propagation. They generally based these ideas on their experiences with a single project or a small number of projects that represented each characteristic. Four activities were most prominent in the codes:

- **Immersive workshops.** Program directors felt immersive workshops with follow-up communication promote adoption. To maximize the impact of the workshops, they should be all-expenses paid, week-long immersion experiences, with a
follow-up workshop and communication throughout the implementation between the PI and adopter—and the adopter should add to the PI’s data to continually assess the effectiveness. However, workshops require money and skilled facilitators, both of which are in short supply.

- **Collaborating institutions.** Program directors believed projects involving multiple institutions are more likely to be successfully propagated. Collaborating institutions provide beta sites to assess the innovation during development and also increase the number of faculty with a stake in the work, which helps sustain and propagate the innovation.

- **Extended funding period.** Many of the most successfully propagated projects received funding over an extended period (often 10 years or more) through a series of grants. They mentioned projects that moved from type 1 to type 2 grants, allowing for more dissemination efforts. However, they also acknowledged a tension within NSF between providing additional funding for existing projects and providing funding for new projects.

- **Professional societies.** Program directors believed professional societies can play key roles in propagation, by promoting specific innovations or, as in the case of physics, hosting programs such as the New Faculty Workshop to expose many potential adopters to innovations.

### iii. Barriers to propagation

Program directors identified several general barriers to propagation. Three barriers were most prominent in the codes:

- Many innovations do not have sufficient evidence of efficacy to convince STEM instructors to adopt them. Program directors felt that projects should pay more attention to collecting evidence of efficacy. For example, in the biology and engineering discussions, program directors believed faculty want to see demonstrated effectiveness, and see efficacy as a reason to change practice. The mathematics program directors believed more beta sites would help with adoption, because then more than one site is involved and there is more evidence of effectiveness.
Many disciplines do not have professional societies that promote innovative teaching. Some disciplines (e.g., physics) have centralized, influential professional societies that aid in dissemination, but this should occur in more disciplines.

The nature of some disciplines was seen as not conducive to propagation. For example, the large size and larger number of subdisciplines within engineering and biology make propagation difficult. The place-based nature of geoscience meant that many grants are developed for a particular location and may not be appropriate for propagation to a different geographic area.

Phase 1 Conclusions

The PI comments provided several insights. First, PIs want to institutionalize their innovation and disseminate to a broader audience outside their institution. Second, PIs think about dissemination mostly in terms of impersonal, “mass-media” mechanisms such as publishing papers or giving conference talks. Third, PIs separate development of the project and dissemination into distinct project phases, one of which (development) is most important and should occur within the grant funding period, and the other (dissemination) is less important and can appropriately occur after the grant funding period. The results illustrated what much of the literature and anecdotal experience in the field has long suggested: education researchers do not consider dissemination until near the end of a project when much of the work has already been completed, and they rely on traditional academic channels (i.e., talks and papers) to inform others about their work (Khatri et al., 2013). The goal of this phase of research was to understand typical propagation practices. From the results, we suggest the following propositions:

- Proposition 1: Principal investigators focus most of their attention on product development. Dissemination occurs after development, if at all.
- Proposition 2: Principal investigators think of dissemination in terms of impersonal, “mass-media” mechanisms such as publishing papers or giving conference talks.

The program directors’ input bridged typical and successful practice through their firsthand knowledge of typical grant outcomes along with their experience with a few grants that had been successful in creating large-scale change. They noted that many typical PIs submitted
grants on their own, with no collaborations, and that grants with multiple collaborating institutions had a greater chance for institutionalization at those multiple sites.

The program directors had the same basic framework for propagation (development followed by dissemination) as expressed by the PIs, but strongly emphasized collaborations and hands-on approaches to disseminating. This mirrors what is known in change literature about opportunities for the developers to get feedback and beta testing (Burkhardt & Schoenfeld, 2013) and opportunities for adopters to engage with an idea before being persuaded to try it and implement it (Rogers, 2003). Research also indicates that instructors want to be involved in the development process of new strategies (Henderson & Dancy, 2008) and that propagation should begin at the start of a project through interactivity between instructors and developers (Dearing & Kreuter, 2010). From the program directors, we suggest two more propositions:

- Proposition 3: Program directors think about education development projects as a development phase followed by a dissemination phase.
- Proposition 4: Program directors strongly emphasize the importance of interactivity in both development and dissemination.

Phase 2

The goal of phase 1 of this project was to understand typical dissemination practices of education developers. We now turn to phase 2 with the goal of understanding successful dissemination practices by examining in detail three projects that have been widely implemented.

Phase 2 Methodology

In order to develop a model of designing for successful propagation, it is important to study instances of successful propagation. Practices leading to successful propagation will be particularly useful when contrasted against typical practice. In phase 2 we studied three successfully propagated instructional strategies within college physics and chemistry. The sections below detail the selection of cases, the data collection, and the analysis for this phase.
Purposeful Selection of Cases: Three Well-propagated Instructional Strategies that Vary in Type of Change

i. Identifying well-propagated instructional strategies

The three instructional strategies were selected from a pool of branded well-propagated instructional strategies ($N=19$) intended for undergraduate STEM instruction (Khatri, Henderson, Cole, Froyd, et al., 2015). This list of well-propagated instructional strategies was developed by the authors through an email survey of 39 experts from seven STEM disciplines. The details of the process to identify experts and of the survey are described in a forthcoming article (Khatri et al., 2017). Results from the expert survey were corroborated using other evidence of propagation, such as the number of nondeveloper sites using the strategy, publications about the strategy by nondeveloper instructors, spread to other disciplines outside the originating discipline, and visible signs of a network of users such as an active online presence or physical conferences devoted to the strategy. The list of well-propagated instructional strategies is available at our project website (Henderson et al., 2015).

ii. Selecting strategies that vary in change required to adopt

The three instructional strategies used in this study were selected from the larger list to represent different degrees of cooperation (e.g., between individuals or departments), resources (e.g., money, institutional space), and change to teaching practices required for implementation. These measures (described for each instructional strategy in Table 3.2 below) were developed by the project team to explicitly discuss features of different educational innovations (Henderson et al., 2015).
Table 3.2 Types of change required of potential adopters to adopt the three cases discussed

<table>
<thead>
<tr>
<th>Change required</th>
<th>Cooperation required</th>
<th>Resources required</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PhET Interactive Simulations</strong></td>
<td>None: Individual instructors can adopt the innovation with no involvement of other instructors or the institution.</td>
<td>None: No additional resources are required.</td>
</tr>
<tr>
<td>None: Individual instructors can integrate materials into their class without modifications to their typical teaching approach or syllabus content; no time beyond usual lesson planning is needed</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Peer Instruction</strong></td>
<td>None: Individual instructors can adopt the innovation with no involvement of other instructors or the institution.</td>
<td>None: No additional resources are required.</td>
</tr>
<tr>
<td>Some: Individual instructors need to adjust their teaching approach or make modifications to material normally covered in the syllabus, and spend time both learning about and implementing the product</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Peer-Led Team Learning</strong></td>
<td>Some: Requires cooperation of at least one other instructor and may involve departmental or institutional approval.</td>
<td>Some: Some additional resources (e.g., a few small pieces of new equipment, an undergraduate student assistant) may be required</td>
</tr>
<tr>
<td>Moderate: Individual instructors need to adjust their teaching approach and the way they run class, modify the syllabus substantially, and spend time learning about and implementing the product</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The degree of change required by adopters is thought to be an important variable in the likelihood of successful implementation (a “smaller” change to typical teaching practice might be easier to implement than a “larger” change to practice) (Henderson et al., 2012). This range in degree (from no change to moderate) was desired in building a model applicable to a wide variety of instructional strategies. We wanted to see if innovations with different degrees of change use similar or different strategies to varying success in their own contexts. The instructional strategies were also selected based on their widespread adoption in and applicability to a wide variety of STEM disciplines. In the following sections we briefly describe each of the three well-propagated strategies that we studied.
iii. Descriptions of selected cases

Peer-Led Team Learning (PLTL) is an instructional strategy that retains lecture and replaces recitation with weekly “workshops” facilitated by a peer leader (an undergraduate student who has done well in the course) (Gosser et al., 2001). PLTL resources offer guidelines about what kind of student makes a good leader, weekly training of peer leaders, types of materials to use in workshops, appropriate faculty roles in developing materials and training leaders, and suggestions on small variations to adapt the program to different institutional settings. Critical components for successful implementation of PLTL include keeping the workshops to 6–8 students, making the workshop integral to the course, and ensuring that the program is supported by the department and institution (Gafney & Varma-Nelson, 2008). The program first started in 1991 as an idea of “collaborative-learning groups to improve student success at the City College of New York (CCNY)” (Gosser, Kampmeier, & Varma-Nelson, 2010). The idea began under an initial NSF grant and has impacted over 100 institutions (Gosser et al., 2010).

PhET Interactive Simulations are highly flexible, freely available simulations developed to depict physical systems which allow students to alter variables and view the results. Simulations have been developed for a large number of physics and astronomy concepts (with more recently added simulations in chemistry, geoscience, biology, and mathematics) (W. Adams et al., 2008). Each simulation presents a particular physical system in which many things can be changed, measured, and explored. The simulations include multiple representations and provide immediate, dynamic feedback in response to user interactions. PhET simulations can serve a variety of instructional uses (e.g., classroom demonstrations, student labs, student homework). PhET began in 2002, founded by Nobel Prize winner Carl Wieman, and the team continues making new simulations today. PhET simulations are widely used and have resulted in over 200 million downloads (“PhET: Free online physics, chemistry, biology, earth science, and math simulations,” accessed 2015).

Peer Instruction is a pedagogy that modifies a typical lecture course (Mazur, 1996). In a Peer Instruction class, the instructor delivers a brief lecture and then poses a multiple-choice conceptual question to the class about the topic. Students have an opportunity to think and respond individually, often using “clickers.” If the students’ answers are varied, they have an opportunity to speak to each other (hence “Peer Instruction”) to discuss their answers and
convince each other of the correct answer. They then respond to the question again, and if the topic is better understood on this round of answers, the instructor moves on to the next topic. Peer Instruction has been shown to improve student learning in a variety of instructional contexts (Fagen, Crouch, & Mazur, 2002). It has been heavily championed by its developer, Mazur, and his research group at Harvard. Its influence is far reaching and documented in literature (Crouch & Mazur, 2001; Cummings, 2011; Henderson, 2008), including adoption in other disciplines besides physics (for example computer science, where other researchers have been promoting it (Simon, Kohanfars, Lee, Tamayo, & Cutts, 2010).

Data Collection

To conduct in-depth investigations of the three chosen strategies, we used qualitative methods (Charmaz, 2006; Creswell, 2007; Miles & Huberman, 1994; Saldaña, 2012; Yin, 2009). As discussed above, prior research has identified each of the three instructional strategies as being very successfully propagated. Thus, we did not seek to document the extent of propagation, but rather document the actions of the developers that led to this successful propagation.

Multiple data sources allow the researcher opportunities for triangulation, or checking one source of data against another in a chain of evidence for claims. The sources of data for the three strategies are summarized in Table 3.3.
Table 3.3 Summary of data sources used in the studies of well-propagated strategies

<table>
<thead>
<tr>
<th>Data Sources</th>
<th>PLTL</th>
<th>PhET</th>
<th>Peer Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary data sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interviews</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Other artifacts</td>
<td>Book (Gafney &amp; Varma-Nelson, 2008)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Secondary data sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press Releases</td>
<td>n/a</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Videos</td>
<td>n/a</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Academic articles</td>
<td>1 (Gosser et al., 2010)</td>
<td>5 (Adams et al., 2008; Adams et al., 2008; Perkins et al., 2006; Wieman et al., 2010; Wieman, Perkins, &amp; Adams, 2008)</td>
<td>3 (Crouch &amp; Mazur, 2001; Fagen et al., 2002; Lasry, Mazur, &amp; Watkins, 2008)</td>
</tr>
<tr>
<td>Grant Proposals</td>
<td>n/a</td>
<td>3</td>
<td>n/a</td>
</tr>
<tr>
<td>User’s Guide</td>
<td>1</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>Presentations</td>
<td>n/a</td>
<td>1</td>
<td>20</td>
</tr>
</tbody>
</table>

PLTL already had a detailed study of its dissemination, carried out and recorded in a 2008 book by Varma-Nelson and Gafney (Gafney & Varma-Nelson, 2008). This study is the product of ten years of interviews and site evaluation data. This provides the story of PLTL from its inception to institutionalization at more than one hundred other departments, in different
disciplines and types of institutions. We interviewed the authors of the book for more detail on the development of the PLTL project since the research by Varma-Nelson and Gafney mostly focused on the results of implementation. One of the book authors, Varma-Nelson, was also one of the original developers of PLTL. Other data sources included the PLTL website (“The Center for Peer-Led Team Learning,” n.d.) and the PLTL guidebook (Gosser et al., 2001).

For PhET, we conducted interviews ($N = 4$) with members of the PhET team, including current and past faculty researchers involved with the project and a programmer involved for many years. Other sources of data included grant proposals, academic publications, presentations, YouTube videos, press releases, and other publically available information. The interviews provided an initial sense of the project in the first round of coding, and evidence from the document data was used to corroborate points made in the interviews.

The methodology used for the Peer Instruction study was similar to that of the PhET study, although there was a difference in the available document data. The PhET team was able to send grant proposals for the project, which helped outline early events. Peer Instruction, being a decade older than PhET, began in the era of paper grant proposals which were no longer accessible. However, there were hundreds of presentations made by the Mazur group that are freely available online. This data source was important in developing an understanding of the history of Peer Instruction. The sources of data were, in order of relevance, interviews with members of the Peer Instruction team ($N = 4$), PowerPoint documents for workshop and colloquium presentations delivered over a fifteen year period ($N = 20$), the Peer Instruction User’s Manual (Mazur, 1996), videos of talks available on YouTube, academic publications about Peer Instruction, and press releases.

Interviews were used as a primary data source in all three cases. They ranged from 30 to 90 minutes, were conducted over the phone or in-person and recorded, then transcribed verbatim. Interviews were semistructured, using a standard protocol across interviews and cases (questions included asking participants what they believed to be key events in the project’s timeline and their personal involvement) but allowing for follow-up questions during the interview. Other documents were used as secondary data sources to confirm connections made from the interviews. Finally, the interviewees were asked to read over early write ups and make comments to ensure the findings represented their views and were factually accurate. When questions arose from other sources of data, interviewees were contacted via email to clarify.
Analysis

Analysis was an iterative process with multiple rounds of coding. Initial narrative analyses of these data sets are described elsewhere (Khatri et al., 2014). This narrative provided context during the aggregate analysis phase, which aided the researchers in making connections. We note that the narratives showed there were commonalities across the three separate cases, even though they represent different degrees of change—all three were multiyear, multigrant, with distinct similar key events.

The analysis presented here for this grounded theory study focuses on propagation activities through a more detailed documentation of the actions and beliefs of the project teams. This delineation of documenting what the interviewees did and what their thoughts on those actions were is a strategy from grounded theory methodology, in which “process coding” is used to identify action words (Saldana, 2012). The coding process began by identifying all of the actions and beliefs in each of the interview transcripts and selected documents. Actions and beliefs were coded separately, which meant they could overlap (and could subsequently be examined for co-occurrence). To be coded as an action, a segment of text needed an action clause or verb such as “we did that for a while…” or “we ran workshops there.” To be coded as a belief, segments needed a clause such as “that was important because…” Doing this thorough coding of every action allowed us to characterize all the activities described, and coding the beliefs separately allowed us to draw attention to the actions associated with beliefs. Once the actions were identified from the interview transcripts (and, in the case of PLTL, published documents) they were triangulated with the secondary data sources.

Codes were developed to capture the range of actions and beliefs. Terms from the phase I codes, categories, and propositions were used when possible (e.g., “Dissemination — giving colloquia” or “Development—interviewing students”). If an action or belief did not fit into an existing code, new codes were formed to capture the idea from the text. Two researchers coded several documents separately and discussed differences in coding decisions, which led to more descriptive and consistent codes.
Phase 2 Results

The following results describe the categories developed in the coding process with codes, their definitions, and quotes to illustrate an instance of the codes. Figure 3.4 provides an overview of the coding system, with the four main categories on top and frequently mentioned codes associated with each category.

![Figure 3.4 Overview of the coding system hierarchy]

Overview of Results

Four categories of actions emerged from the coding process (Table 3.4). The first two categories (development, dissemination) were carried over from phase 1. Two additional categories (funding, support) emerged when actions did not fit into the phase 1 categories.

The following sections present the results of phase 2 for the primary categories: development, dissemination, support, and funding. Within the primary categories we discuss the most prominent codes and make connections with the results from our characterization of typical practice from phase 1 of the study. Also reported are the number of times interviewees expressed
a belief that the action contributed to the success of the project. Separating beliefs from actions aided analysis in drawing attention to those actions that interviewees felt were important, and conversely also allowed for more impartial analysis of the actions themselves by filtering out the beliefs and viewing the actions alone. Discussion of belief codes will be presented along with the relevant action codes.

Table 3.4 Categories used in coding interviews from the three well-propagated strategies

<table>
<thead>
<tr>
<th>Category</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development</td>
<td>Activities of developing a project or product, including implementing and testing</td>
</tr>
<tr>
<td>Dissemination</td>
<td>Activities of telling others about the project and product, including strategies for doing so</td>
</tr>
<tr>
<td>Support</td>
<td>Activities of providing materials or advice to help users be successful in their implementation</td>
</tr>
<tr>
<td>Funding</td>
<td>Activities of getting grant or nongrant funding, uses for funding, or considering new mechanisms to sustain funding</td>
</tr>
</tbody>
</table>

Counts (out of 914 coded actions)

Category: Development

Development activities across interviews generally had heavy overlap with dissemination activities, in the form of secondary implementations. This is in contrast to the solitary development (one site only or limited sites) observed in the typical practice of PIs. The codes listed in Table 3.5 are described below. The counts represent the number of times an action was coded and the number of times the subcode belief “contribution to success” associated with that action was coded.
<table>
<thead>
<tr>
<th>Code</th>
<th>Code meaning</th>
<th>Count</th>
<th>Belief count</th>
<th>Example quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing and feedback</td>
<td>Testing the instructional strategy (both within and outside of the original team) and collecting data from faculty and students</td>
<td>97</td>
<td>17</td>
<td>… a data-driven approach to develop the modules instead of just picking modules that we think that people would interact with and like.. we test that first and then use that specific content within the modules. (Peer Instruction team member 3)</td>
</tr>
<tr>
<td>Hiring personnel</td>
<td>Hiring staff to help with the project or targeted hiring decisions</td>
<td>31</td>
<td>3</td>
<td>And so we brought together content experts educational research experts and programming design experts altogether in these design teams which makes the project product fairly unique in design. (PhET Team Member 3)</td>
</tr>
<tr>
<td>Identifying design principles</td>
<td>Identifying the key features ideally seen in implementations</td>
<td>29</td>
<td>5</td>
<td>And basically the broad conclusions we drew were that first of all it was really important that people have students both think about the questions, commit to answers on their own, and have students discuss them. (Peer Instruction Team Member 3)</td>
</tr>
<tr>
<td>Research</td>
<td>Conducting education research that goes beyond (and often complements) formal testing and feedback</td>
<td>24</td>
<td>6</td>
<td>And then finally I also started a project which was then finished by others after me on examining whether teaching with peer instruction made a difference in terms of success of male and female students. (Peer Instruction team member 2)</td>
</tr>
<tr>
<td>Changing roles within project</td>
<td>Project staff taking on additional or different responsibilities within project</td>
<td>16</td>
<td>0</td>
<td>When people had implemented and finished the year. We would even give them our slides. [...] And we would get lots of invitations and instead of going all the time we would find whoever was in the region and say “here are the slides, go talk.” (PLTL team member 1)</td>
</tr>
</tbody>
</table>
i. Testing and feedback and identifying design principles

Testing and feedback of the strategy, by methods such as collecting data from use in the developer’s classroom (25 mentions), use in other classrooms (23 mentions), and from student interviews (19 mentions), was discussed frequently in interviews. Eight interviewees explicitly mentioned (17 times) that this was an important contributor to the overall success of the project. Formal collaborations such as the PLTL consortia and informal collaborations with secondary implementers and other parties provided these testing grounds. Further, testing and feedback led to identifying design principles, as illustrated by both PLTL and PhET.

- The PLTL team used NSF grants to establish two consortia of institutions using PLTL. With the pool of data from these institutions, and the aid of the external evaluator, the team developed a list of “Six Critical Components” for a successful implementation of PLTL (Gosser et al., 2010).

- The PhET team spent several months of developing simulations (around ten), and then used this experience to identify basic tenets of design elements (Adams et al., 2008). This includes the “look and feel” (“PhET Look and Feel,” n.d.) of a simulation, the iterative development process (learning goals, first design, student testing and interviews, classroom use, redesigns), and the expertise required (content, programming, and education experts.) Interviews with students proved to be invaluable in interface design (Adams et al., 2008).

The phenomenon of identifying formal design principles after a testing period is also seen to some extent in the development of Peer Instruction, as illustrated by the following quote:

“And what we were trying to get at there was a sense of what was the range of ways in which people implemented Peer Instruction and […]—were they effective? And basically the broad conclusions we drew were that first of all it was really important that people have students both think about the questions, commit to answers on their own, and have students discuss them. There were some people who were running Peer Instruction in a sort of mode where it was sort of a quiz mode, and it was not about learning from the questions but it was sort of quizzing students with the questions, and that did not seem to be successful.” (Peer Instruction team member 2).

In this quote, the team learned from other implementations what practices worked less well, leading to the identification of practices that were more successful. This mirrors the
formation of critical components in PLTL in which less successful implementations were compared with successful ones:

“We had not yet thought of the critical elements. We were just saying, ‘What is it that is making some programs successful and others not?’ and we kept looking at the group size. And there were places where they were putting in 20 students with one peer leader and that is never going to work.” (PLTL team member 1).

Comparison of implementations enabled PLTL to identify reasons some implementations were successful, such as having smaller groups versus larger groups. Group size then became one of the critical components to successfully implement PLTL.

For all three cases, testing the new innovation with students and in other settings allowed the project teams to identify design principles for an ideal implementation.

ii. Hiring personnel and changing roles

Intertwined with testing, feedback, and design principles is the staff involved with doing so (31 mentions). Notably, the use of an external evaluator for PLTL and different expertise in PhET contributed to identifying design principles. Other staff, especially prominent in the case of Peer Instruction, is included in the form of graduate or postdoctoral researchers carrying out additional education research within the project (24 mentions). Often, team members take on new roles, especially leadership roles (16 mentions.) We note that in typical practice, the project may not exist long enough for roles to change. In these successful multiyear projects, though, roles often did change. This may contribute to project sustainability.

iii. The role of research

Research activities associated with the same grants or research group were coded separately from testing and feedback activities. Research is distinct from the other program activities because the purpose of education research is to discover new knowledge in science education. Testing and feedback activities for the innovation can overlap with this goal but are usually more focused on the specific context of the product rather than on generalizable knowledge. Research activities could take the form of testing specific aspects of the innovation in different contexts, or using the innovation in connection with another research question (such as how the innovation impacts certain groups of students). Three interviewees linked research
activities to the success of the project, believing it helped validate the project in the eyes of potential adopters.

Category: Dissemination

The codes given for the dissemination category in Table 3.6 are described in the sections below.

Table 3.6 Frequently used codes and example segments for the dissemination category

<table>
<thead>
<tr>
<th>Code</th>
<th>Code meaning</th>
<th>Count</th>
<th>Count</th>
<th>Example quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engaging in dissemination activities</td>
<td>Any mention of specific dissemination activities or strategies</td>
<td>179</td>
<td>40</td>
<td>It was really just word-of-mouth and collegial activity that brought the program to the attention of [institutions] and a couple of other places… (PLTL team member 1)</td>
</tr>
<tr>
<td>Spreading to new audiences</td>
<td>Any mention of the instructional strategy spread to new audiences, e.g. other disciplines, languages</td>
<td>40</td>
<td>7</td>
<td>We also expanded to middle school, so, that was another key event, so kind of growing first in discipline and then growing in grade level down to K-12, explicitly down through K-12 and, they were being used a lot in high schools as well as university, like jumping all the way down to middle school. (PhET team member 1)</td>
</tr>
<tr>
<td>Creating philosophy of dissemination</td>
<td>Philosophy of dissemination developed or acted upon</td>
<td>31</td>
<td>12</td>
<td>I think look at the model. That four-tier model. That really when operationalized that really the key thing there is creating new leaders. And I think we did that quite effectively. Is we did give, it wasn't centralized. There wasn't just one person talking about PLTL, and that I think</td>
</tr>
</tbody>
</table>
Table 3.6—Continued

<table>
<thead>
<tr>
<th>Code</th>
<th>Code meaning</th>
<th>Count</th>
<th>Belief Count</th>
<th>Example quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honing presentation</td>
<td>Editing and changing materials used in dissemination</td>
<td>20</td>
<td>7</td>
<td>We spent a lot of time on those talks and at the end of every talk, there was always a lot of work that went into it. (Peer Instruction team member 4)</td>
</tr>
<tr>
<td>Interaction with publishers</td>
<td>Any interaction with a publishing company</td>
<td>14</td>
<td>3</td>
<td>We eventually made them open, so both commercial and noncommercial companies, for free, so that ended up resulting in [...] integrating the PhET Simulations, so that helped get them in front of more students and teachers. (PhET team member 1)</td>
</tr>
</tbody>
</table>

i. Engaging in dissemination activities

Project teams engaged in a wide variety of dissemination activities—these are reported in a separate table of codes below in Table 3.7.

Table 3.7 Frequently used codes and example quotes for the dissemination category

<table>
<thead>
<tr>
<th>Subcode</th>
<th>Code meaning</th>
<th>Count</th>
<th>Belief Count</th>
<th>Example quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giving presentations and talks</td>
<td>Any talk, including colloquia, invited or contributed conference talks, other</td>
<td>44</td>
<td>14</td>
<td>I relentlessly and tirelessly continued to disseminate the method by giving talks. (Peer Instruction team member 1)</td>
</tr>
<tr>
<td>Subcode</td>
<td>Code meaning</td>
<td>Count</td>
<td>Belief Count</td>
<td>Example quote</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>-------</td>
<td>--------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Running workshops</td>
<td>Any kind of workshop, including half-day and multi-day</td>
<td>30</td>
<td>5</td>
<td>And then we would go and do it again somewhere and there they were again. Some of the same faces kept showing up. And they didn't do it. And then we started doing three-day workshops. (PLTL team member 1)</td>
</tr>
<tr>
<td>Hosting a website</td>
<td>Creating a website to post materials</td>
<td>22</td>
<td>5</td>
<td>So the first website was pretty really basic and then later another website that had more navigation and [...] you could see thumbnails and the abstracts so as the project kind of moved forward... We put more and more attention into the website and how people access the sims. (PhET team member 2)</td>
</tr>
<tr>
<td>Publishing articles</td>
<td>Publishing in peer-reviewed journals and conference proceedings</td>
<td>20</td>
<td>2</td>
<td>And plus you know it's not just us. Other people have also written papers, right. So there are quite a few papers. (PLTL team member 1)</td>
</tr>
<tr>
<td>Dissemination strategies (other)</td>
<td>Any rarely used/new strategy</td>
<td>17</td>
<td>3</td>
<td>So, I thought, “What we really need to do is we need to have a sort of visual workshop.” I had the idea of doing an interactive DVD that would teach people how to implement Peer Instruction. (Peer Instruction team member 1)</td>
</tr>
</tbody>
</table>
The propagation activities used by the teams of successfully propagated projects overlap with the propagation activities listed by PIs of typical projects—PIs also mentioned publications, talks, websites, and workshops as ways to disseminate. The difference between typical and successful practice appears to be the magnitude of those activities.

**Giving presentations and talks**

All three cases mentioned talks and presentations as main modes of dissemination. Participants from the Peer Instruction team believed presentations contributed to the successful propagation of the project.

- Peer Instruction was disseminated directly to many physics faculty through departmental colloquia. The importance of these talks in dissemination was expressed by multiple interviewees. The Peer Instruction team has given over 600 talks, many of them as invited colloquia or featured conference presentations.
- The PhET Simulations also benefitted from invited talks: Carl Wieman was continually invited to speak about his research and used those talks as opportunities to discuss PhET.
- PLTL encouraged faculty who had implemented it to publish and present on their experience. This allowed newcomers to the program to have a stake in it, and their publications and presentations could contribute to their careers as well as the spread of PLTL. This was the “creating scholarship and leadership” step in their model for dissemination (Gosser et al., 2010).

We note that while the activity of “giving talks” is shared by typical and successful practice, there are differences in the prestige and the number of talks being given. Featured talks by Wieman reached a large number of people due to his prestigious status as a Nobel laureate. The colloquia given by the Peer Instruction team are also different dissemination vehicles than a typical conference talk for two reasons: they allow the speaker more space to tell a compelling story, and they engage the whole department at one time. These points about story helping to create change and using a department as a unit of change are both seen in the literature (Heath & Heath, 2010; Wieman, Perkins, et al., 2010). The new scholars and speakers of PLTL may not have had access to prestigious venues but there were many people talking about it besides the original founding team.
Running workshops

All three teams ran workshops, with varied results.

- The PLTL team ran numerous workshops—ranging from short, introductory workshops to multiday, in-depth workshops—but found that other instructors were not adopting PLTL after these experiences, despite the evidence of effectiveness and the involvement of peer leaders (undergraduate students) at the workshops to demonstrate the program. They found that people kept returning to talks and workshops without having put PLTL into place—this led to the creation of their own dissemination framework (Gosser et al., 2010), in which workshops were necessary to impart information but not sufficient to promote use.

- The PhET team gave workshops both locally to high school teachers and nationally to faculty, but found them to not be an efficient way to reach large numbers of people, even though they helped the individuals who attended.

- The Peer Instruction team has been involved with the Physics and Astronomy New Faculty Workshop since its beginning, which helped spread awareness of Peer Instruction. Says Mazur, “Also, the New Faculty Workshop was probably responsible for triggering many invitations. Because the junior faculty would hear me at the New Faculty Workshop, get excited at my talk, and then invite me to come to their home institution.”

In typical practice and in the views of the NSF program directors, workshops were viewed as the best possible dissemination method. The three cases here show that they work well for training people (in the case of PhET) and getting people interested in learning more (PLTL and Peer Instruction.) However, none of the three teams were entirely satisfied with workshops alone as their main dissemination vehicle.

Hosting a website and publishing articles

These methods of dissemination, mentioned by all three project teams, aligned with the methods used by PIs in phase 1. Some project team members spent considerable time preparing manuscripts attached to the research activities of the projects. PLTL was notable in encouraging...
secondary implementers to write about using the strategy, again as part of “encouraging scholarship and leadership.”

*Other methods of dissemination*

All three teams used several creative methods of dissemination that were not mentioned by PIs or PDs in phase 1.

- The PLTL team created usable materials, such as a guidebook, and ran a “mini-grant” program. Interested institutions applied for small grants from this program to begin PLTL programs at their own institutions, which required money to pay the peer leaders. Part of the application was getting institutional or departmental support to match the amount of the grant, and agreement to submit progress reports. This involvement of the department is mirrored in literature which suggests the department is a key unit of change (Wieman et al., 2010).

- The PhET team found exhibit hall booths an effective way to target new audiences through selected conferences. Other dissemination methods included an online presence through Twitter, Facebook, YouTube, a blog, and a newsletter. Currently they are building a website of support materials for teachers which also will have a community component.

- The Peer Instruction team produced a user’s manual book (Mazur, 1996) a DVD, and is currently building training modules for users online. Like PhET, they have an online presence through a blog and community website.

The common thread between these extra methods is creating supporting materials. These support materials went beyond the main support identified by typical PIs, which was to write a textbook. This is discussed below in the section describing the support category.

ii. Spreading into new audiences

Project teams frequently mentioned new audiences as key events in their projects. These included international audiences through visits, spreading into different disciplines, different grade levels, or translating existing products for greater access.

Each project team had interactions with publishers, with varied results.
• PhET actively reached out to target communities by having an exhibit booth at different conferences: “We ran exhibitor booths and we would tell people about PhET, and that really got out to a lot of people... we got to a point where we never ran into anybody who never heard of PhET, everybody had heard of PhET and was already using PhET, so we weren’t getting any new people.” (PhET team member 1.)

• PhET also pushed into a broader audience through the inclusion of the PhET simulations in major textbooks, regardless of publisher, due to the decision to make the license for the simulations attribution only. This means publishers can print and use the simulations for free as long as they give credit. PhET also spread through the content addressed by the simulations as it branched from introductory physics concepts, to more advanced physics concepts, and eventually into other disciplines, beginning with chemistry (Moore, Chamberlain, Parson, & Perkins, 2014).

• Peer Instruction benefitted from the involvement of the publisher, who freely distributed the Peer Instruction User’s Guide to interested faculty in the first years of the book.

iii. Creating philosophy of dissemination

All three teams, but particularly PLTL and PhET, held beliefs regarding how dissemination and change work and acted on those beliefs, either by writing them down (much like the list of design principles of the product itself mentioned above), or building and presenting the product in alignment with their beliefs.

• The PLTL team explicitly created a four-step strategy for dissemination. They found that people kept returning to talks and workshops without having put PLTL into place. Thinking about the problem, they developed their own dissemination strategy with four steps (Gosser et al., 2010): 1. Stimulating interest, 2. creating a deeper understanding, 3. successful implementation, 4. developing scholarship and new leadership. “Stimulating interest” is accomplished through publications and presentations. “Creating a deeper understanding” can be accomplished through workshops, as the goal is to educate newcomers in the details of the
program. The goal of “Successful implementation” was to put PLTL into place at a new institution. Finally, “developing scholarship and new leadership” encouraged faculty to publish and present on their experience implementing PLTL.

- The PhET team intentionally makes design decisions about the simulations with the goal to keep them accessible and adaptable.

iv. Honing presentation

The PLTL and Peer Instruction teams discussed ways in which they changed their dissemination materials, such as how they delivered talks and workshops, over time as they did these activities. For Peer Instruction, this was mostly how talks were delivered, for example, building in some discussion of barriers:

“My talk initially had focused mostly on the “why,” not on the “how.” It became clear that my “why” was very compelling. I convinced a lot of people of the need to teach interactively. But then, if I did just that, they were left with so many questions that there was always a need for a follow-up. So now, I started to build that in.” (Peer Instruction team member 1).

The PLTL workshops changed once the Six Critical Components existed to incorporate them as key points required for implementation.

Category: Support

Support activities were mentioned less frequently than development and dissemination activities, and interviewees tended not to express strong beliefs about their efficacy. Like the categories of development and dissemination, support activities can overlap with other activities. The codes from Table 3.8 are described more fully in the sections below.
Table 3.8 Frequently used codes and example quotes for the support category

<table>
<thead>
<tr>
<th>Code</th>
<th>Code meaning</th>
<th>Count</th>
<th>Belief Count</th>
<th>Example quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating instructor support</td>
<td>Providing ready-made materials and practical advice</td>
<td>23</td>
<td>6</td>
<td>…right now we have active efforts to create the PhET teacher website which is going to be a website that really…is designed to support teachers, so it’s not just the simulations. (PhET project team member 1)</td>
</tr>
<tr>
<td>barriers to adoption</td>
<td>Anticipating or discussing possible problems in implementation with adopters</td>
<td>15</td>
<td>1</td>
<td>The PLTL founding group of faculty prepared a Guidebook and a Peer Leader Handbook which was published by Prentice Hall and was very helpful in reducing the barriers to implementation as they were distributed free of charge to new and potential adopters of the model. (PLTL book)</td>
</tr>
<tr>
<td>Direct training and site visits</td>
<td>Hosting visitors or visiting other institutions to offer direct assistance and training</td>
<td>11</td>
<td>0</td>
<td>So we support more than just the money. We would always, we would go to their schools and talk to their deans and all kinds of things. And [we] did a lot of traveling. (PLTL project team member 1)</td>
</tr>
<tr>
<td>Maintaining product</td>
<td>Keeping the product updated and functional over time</td>
<td>7</td>
<td>1</td>
<td>…and being able to target more platforms such as mobile devices like iPads and android tablets. (PhET project team member 4)</td>
</tr>
</tbody>
</table>

i. Creating teacher support or resources

As mentioned above in the dissemination section, all three project teams created some kind of teacher support or materials, especially ready-made materials.

- As mentioned above, the PLTL team developed many supporting materials for interested instructors, such as the guidebook and other short guides to implementation. The guidebook (Gosser et al., 2001) includes details about how
to run the program, how to select and train leaders for the program, and it provides example problem formats for group work. The book includes testimonials from peer leaders and instructors on the positive impacts of PLTL.

- The PhET website already has numerous activities for teachers surrounding individual simulations (which teachers can upload and contribute to), but the team is also making a new website for teachers, using their body of research on how to best use the simulations with students. This website (in production) also has a goal of building a community of teachers.

- The Peer Instruction team has a community website with some materials explaining what Peer Instruction is and tips for successful implementation. A separate group of computer science educators have created a support website for Peer Instruction in a computer science setting, with advice for implementation and slides of material for specific courses (Bailey Lee & Simon, n.d.).

We note that some of these activities (particularly the original Peer Instruction website) were viewed by the team members as activities that were not very successful, or could be successful with more funding and manpower to foster a community of instructors adding their own resources.

ii. Addressing barriers to adoption

This action was mostly undertaken by the PLTL team. They learned from interacting with interested potential adopters that the program seemed too challenging to put into place, as illustrated by the following quote:

“…and faculty from other places would say, you know, it sounds good, but it also sounds like the invasion of Normandy, and it’s just too much, especially in the case where you know, they might have 400 freshmen in an introductory chemistry class.” (PLTL team member 2).

To address these barriers they developed their own dissemination plan (involving direct assistance to implement the program at a new institution) and the mini-grant program, as one of the biggest barriers mentioned by potential adopters was the funds required to pay the peer leaders.
iii. Direct training and site visits

One activity undertaken by the PLTL and Peer Instruction teams was going to a site directly or allowing outside instructors to come to their institution and learn about the innovation.

- The Peer Instruction team would travel frequently to other institutions for colloquia or occasionally more in-depth interactions. One interview described hosting instructors from another institution at Harvard so they could learn to do it directly from them, then flying out to visit them later to assist in the implementation.
- The PLTL team includes “successful implementation” as step three in their dissemination plan, or to directly aid new implementers to start their own programs.

iv. Maintaining product over time

This activity was mainly seen in the PhET interviews. The team was concerned the pace of technological developments might make simulations unusable, and were looking ahead to different platforms. This was a different activity than other support mechanisms seen in the other two cases, specific to the computer-based nature of PhET.

Category: Funding

The funding category (Table 3.9) is slightly different from the others. While the others have occasional overlap funding was integral to every activity undertaken by the teams. Below is a table (Table 3.10) that presents the top action codes overlapping with “uses for funding.”
Table 3.9 Frequently used codes and example quotes for the funding category

<table>
<thead>
<tr>
<th>Code</th>
<th>Code Meaning</th>
<th>Count</th>
<th>Belief Count</th>
<th>Example quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grant funding</td>
<td>Getting funding from grant sources</td>
<td>46</td>
<td>9</td>
<td>And I think it was a good idea and a good project. So the first project that was funded was Workshop Chemistry. (PLTL project team member 1)</td>
</tr>
<tr>
<td>Uses for funding</td>
<td>Description of how funding was used, e.g., travel, research</td>
<td>30</td>
<td>4</td>
<td>We didn’t get like a special grant just for dissemination, but you know, the funding pays for the website and pays for the conference travel. (PhET project team member 1)</td>
</tr>
<tr>
<td>Nongrant funding</td>
<td>Building new funding mechanisms or getting funding from non-grant sources</td>
<td>25</td>
<td>0</td>
<td>So there’s the user donations and then we’re also working on the commercial donations, like corporate donations. (PhET project team member 1)</td>
</tr>
</tbody>
</table>

Table 3.10 Codes co-occurring with the code “uses for funding”

<table>
<thead>
<tr>
<th>Code occurring with uses for funding</th>
<th>Count co-occurring</th>
<th>Example quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissemination-Dissemination strategies (other)</td>
<td>11</td>
<td>So this was the blog […] supported by the National Science Foundation grant that we got. (Peer Instruction team member 3)</td>
</tr>
<tr>
<td>Support—Direct training and site visits</td>
<td>6</td>
<td>So we tried, actually if you get ahold of our second national dissemination [grant proposal], we wrote it as centers. So there was one center in Chicago […] And then there was one in Montana. There was one in Miami and one in New York. So those were the four centers that we had responsible for each of our regions. (PLTL team member 1).</td>
</tr>
</tbody>
</table>
Table 3.10—Continued

<table>
<thead>
<tr>
<th>Code occurring with uses for funding</th>
<th>Count co-occurring</th>
<th>Example quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support—Instructor support and resources</td>
<td>3</td>
<td>Basically there was the one grant for the website called Project Galileo. […] which was to have it be kind of a course management system before there were course management systems, so that it would have concept tests—just a database of concept tests just built into it. (Peer Instruction team member 2)</td>
</tr>
<tr>
<td>Development—hiring personnel</td>
<td>3</td>
<td>I was the first hire under that, under that title. (PhET team member 4)</td>
</tr>
</tbody>
</table>

Funding was used in development (through paying secondary development sites, and in research efforts, and personnel), dissemination (funds for a website, workshops, travel), and support (funds for travel, publishing materials).

We note that the teams were interested in creating new mechanisms for funding besides grants to continue the projects.

Phase 2 Conclusions

The three cases provided an in-depth look at the activities undertaken by project teams behind well-propagated strategies. The goal of this phase was to understand successful propagation practice. Four additional propositions were developed from these cases.

- Proposition 5: In successful projects, testing and feedback are used to identify the design components.

  Although PhET and PLTL are very different types of innovations, they shared a common pilot testing stage in their projects that led to explicitly stating the design principles necessary for successful use. This suggests the transferability of these findings to other innovations regardless of how easy or difficult they are to implement.

- Proposition 6: Successful projects engage in traditional mass-media dissemination. In contrast to typical projects they do traditional dissemination at a
large scale and also have more interactive and creative dissemination mechanisms.

The three project teams also aligned with the typical PIs regarding the types of dissemination activities undertaken, but found ways of making talks, in particular, more effective for their innovation. The ways each team gave talks about their projects were unique (PhET benefitted from large-scale invited talks, Peer Instruction from hundreds of departmental colloquia, and PLTL from creating new leadership to give more talks about the project.) One point that aligns with change literature is the impact of an opinion leader (Rogers, 2003), which PhET and Peer Instruction both had. Further, they came up with new ways to disseminate, such as producing a DVD, having an exhibit booth, or using a large dissemination grant to run a minigrant program.

- Proposition 7: Successful projects realize that users need support to be successful.

All projects studied continue to struggle to identify ways to best support users. Through their experiences of interacting with possible adopters, the teams of all projects began to realize that additional support was needed in order for adopters to be successful. Each team discussed efforts to develop support mechanisms. Many of these mechanisms were not highly successful.

- Proposition 8: Successful projects received continuous funding over an extended period of time.

Finally, funding was involved in every category and used in a variety of ways. Funding was involved with development, dissemination, and support activities. This finding is consistent with the view of the program directors that many of the initiatives they recalled as having an impact received funding (over ten years or more) over a series of related grants.

Conclusions

We synthesized the propositions from phases 1 and 2 (summarized in Figure 3.5) in the form of a model for effective propagation activities (Figure 3.6), which educational developers can apply to create a strong transferable product that is likely to propagate.
Phase 1 propositions:
1. PIs focus most of their attention on product development. Dissemination occurs after development, if at all.
2. PIs think of dissemination in terms of impersonal, “mass-media” mechanisms such as publishing papers or giving conference talks.
3. Program directors think about education development products as a development phase followed by a dissemination phase.
4. Program directors strongly emphasize the importance of interactivity in both development and dissemination.

Phase 2 propositions:
5. In successful projects, testing and feedback are used to identify the design components.
6. Successful projects engage in traditional mass-media dissemination. In contrast to typical projects, they do traditional dissemination at a large scale and also have more interactive and creative dissemination mechanisms.
7. Successful projects realize that users need support to be successful. All projects continue to struggle to identify ways to best support users.
8. Successful projects received continuous funding over an extended period of time.

Figure 3.5 Summary of knowledge propositions

Figure 3.6. Tentative model of designing for successful propagation
As discussed in this paper, the model is derived from a survey of principal investigators, focus group interviews with NSF program directors, and context-specific examples of well-propagated instructional strategies in physics and chemistry. Although we expect the general structure of the model to remain, phase 3 of the study will use interviews from more PIs of successful innovations in more disciplines and contexts and may result in further elaboration of the model to provide context-specific advice for education developers within each stage.

Description of the Model

The model of designing for successful propagation resulting from this study has three core propagation activities: interactive development, interactive dissemination, and support of adopters. Each of these stages is interconnected with the other stages and each stage relies on funding. The following sections use examples from phases 1 and 2 to describe each of the three stages.

Interactive Development

Often, a new teaching strategy is developed in a single context. Developers may discuss the strategy with others in their department or even have a local collaborator. However, there is little or no interaction with potential adopters at other institutions.

Instead, this model suggests that successful developers create and refine a new instructional strategy with collaborators and (or) potential adopters. Interactive development involves getting feedback from the beginning, possibly a trial period collecting data from other implementations to strengthen the innovation, and articulating product design principles. With other people involved from the start, there are more stakeholders in the new innovation and also more opportunities for feedback to strengthen the product.

For example, the PhET Simulations accomplished interactive development through student interviews at their own institution and hiring staff in different areas, such as interface design, content expertise, and pedagogy expertise. As the program went on, collaborations were formed with other science content personnel (biology, chemistry, etc.) and other institutions. Peer Instruction, too, used student interviews to inform questions for use in class along with graduate students, post docs, and early collaborations with another institution. For both of these strategies interactive development was accomplished primarily at their home institutions through
the involvement of many people with different perspectives. This is in contrast to PLTL, which involved over ten institutions in interactive development resulting in having a solid format that worked across settings.

Interactive Dissemination

Typical dissemination practice uses academic channels, such as journal articles and conference presentations, almost exclusively. These activities, at best, raise awareness but generally do not result in wide propagation (National Research Council, 2012; Henderson et al., 2012).

Interactive dissemination means engaging the target audience, through immersive workshops and personal connections. This aligns with ideas in the change literature that emphasize the role of interpersonal communication channels (Henderson et al., 2015) and the necessity of thinking about change as a process in which potential adopters require different communication messages at different times (Fullan, 1991). Offering an interactive multiday workshop is an example of interactive dissemination.

Peer-Led Team Learning offered workshops to impart information about the program. Interested instructors attended workshops but encountered barriers implementing the program at their own institution. Recognizing this problem, the team conducted a “mini-grant” program with funds from a large NSF dissemination grant, offering financial support to institutions who wrote proposals that showed they had institutional matching of funds if they received the mini-grant. The mini-grant program stimulated significant interaction between the developers and potential users.

Peer Instruction and the PhET Simulations both benefitted from members of the project team giving numerous invited talks, but also ran workshops. Peer Instruction was spread through sheer quantity of departmental colloquia given as well as involvement in national workshops. Colloquia generated opportunities for personal interactions with people in many institutions.

The PhET simulations team held local workshops for teachers and has open resources to use simulations that instructors can add to. Although these activities were not regarded as successful in spreading PhET by the team, they do show efforts to create a community of teachers using PhET. The team did think of the exhibit hall booths as being successful in letting instructors at targeted conferences know that PhET exists, and doing so through a brief personal
interaction at those communities again speaks to a level of interactivity in the team’s dissemination efforts.

Supporting Adopters

Support is less well understood in the context of higher education than the previous two stages. Education developers do not typically support potential adopters after initial adoption. However, this was seen as a problem by interviewees associated with the successful projects and is also reflected in the change literature (Henderson et al., 2012). The model suggests that support is necessary to provide assistance to adopters as they attempt to use the innovation. An example of support is people being available to consult after a potential adopter starts using an innovation.

The Peer Instruction team offers direct support to potential users, and in recent years has shifted talks about the pedagogy to include more discussion of the barriers instructors may face putting it into place. Both PLTL and Peer Instruction developed user’s guides to give adopters more details and advice on how to implement the strategy; the PhET Simulations, too, offer lesson plans for specific simulations. The PhET Simulations place emphasis on accessibility, as seen in their licensing decision (which allows textbooks to use them free) and in their efforts to keep the simulations running on current technology. More research is needed to identify a broader range of productive support mechanisms.

Future Work

The third phase of this study will use purposeful sampling to further test and potentially expand the model. As an example of how we will use purposeful sampling, consider the potential role of prestigious project leadership in successful propagation.

Two of the three cases discussed above, PhET and Peer Instruction, had the benefit of prestigious leadership (PhET was started by a Nobel laureate, Peer Instruction by a successful Harvard physics professor). Change literature suggests that prestige can be a factor in decisions to adopt a new innovation (Rogers, 2003). In our study we found that, in these cases, frequent well-attended talks, colloquia, and workshops were key methods of informing the physics community that these innovations existed, and prestige may have allowed for access to these
platforms. However, it is also clear that prestige is not necessary for successful propagation: the case of PLTL shows that nonprestigious leadership can propagate a new innovation successfully.

To unpack the role of prestige, whether it allowed for greater access to dissemination mechanisms or itself was necessary for others to adopt innovations, the next phase of research will seek confirming and disconfirming cases. We will investigate (i) typical PIs at the end of their funding period to see if they undertake similar dissemination activities as those mentioned here and (ii) cases of other successful (but less prestigious) PIs to further add and compare to the current model.

Implications for Education Developers

Although we plan to further test and refine the model of successful propagation in phase 3, we feel that there is sufficient strength in the core aspects of the model to allow us to draw three broad implications for education developers.

Implication 1

Education developers typically seek to develop a polished product before getting feedback. Instead, early feedback on incomplete products from potential users is crucial to building a strong product based on explicit design principles.

Developing an innovation with potential adopters (interactive development) increases the likelihood a stronger product. This matches a point from the literature: Many physics instructors are genuinely interested in changing their teaching practices and using novel materials (Dancy & Henderson, 2010). Researchers often expect instructors to adopt finished products without engaging those instructors in the development, and then blame the instructors for making changes in the strategy during implementation (Henderson & Dancy, 2008). Our findings suggest that enlisting interested potential adopters early in the development of new teaching strategies and materials is key in building a strong product with explicit design principles.

Implication 2

Typical education developers rely on communication channels such as journal articles, conference presentations, and websites for dissemination. Successful developers also do these
things but, in addition, find ways to interact with potential adopters and allow potential adopters to interact with their product.

Academic articles and presentations are necessary components of being an academic, and they provide an authoritative source for others to cite. Having research and evidence of student improvement is probably necessary but certainly not sufficient to convince others to adopt an innovation. This is exemplified by workshop attendees of PLTL who needed additional support to actually start PLTL at their institutions. There are other ways of disseminating information, and our model suggests that the more interactive, the more effective. Some suggestions from the three successful strategies: running workshops, using personal connections with other instructors, buying an exhibit booth at conferences, and using invited colloquia to convey a motivational story, with plenty of time for interactions afterwards.

Implication 3

Typical education developers do not plan for supporting adopters during implementation. Successful developers learn about barriers to use through their interactions with people who have tried their product. Successful developers realize that adopters need support during implementation.

Research shows that while instructors are interested in using new instructional strategies, and often try new strategies, they also often discontinue use (Henderson et al., 2012). Supporting adopters can help assuage the problem of discontinuation, as seen in the three cases we studied. In each case the team continues efforts to work with adopters long after the development period. Peer Instruction and PLTL are both over twenty years old and their teams continue to promote them. Support can take place by providing ready-made materials that other instructors can modify, rather than have to develop from scratch (e.g., PhET teacher activities, PLTL guidebook, Peer Instruction User’s Guide). It can also take a more direct form of spending time or money on assisting new implementers.

Interactive development, interactive dissemination, and support of adopters are not typical practice of educational developers, yet appear necessary for successful propagation. The model of designing for successful propagation emerging from this work provides a guide for education developers to construct propagation plans likely to lead to sustained adoption of education innovations.
Acknowledgments

The authors thank the teams behind Peer Instruction, the PhET Interactive Simulations, and PLTL who participated in this study, as well as Tront and colleagues and the program directors who spoke with our team. This paper is based upon work supported by the National Science Foundation under Grants No. 1122446, No. 1122416, No. 1236926.
CHAPTER IV

STRATEGIES THAT SUPPORT SUSTAINED IMPLEMENTATION OF NEW INSTRUCTIONAL STRATEGIES AND MATERIALS

Abstract

Background

A critical problem in STEM education is the lack of adoption of innovative instructional strategies and materials. Numerous strategies and materials have been developed and shown to improve student learning. Many instructors know about these strategies and are willing to try them. However, attempts to use these strategies are frequently not successful. Literature indicates that instructors need support to successfully implement new teaching strategies and materials. Unfortunately, the developers of educational innovations do not always plan for supporting adopters, and the repertoire of support strategies is limited. This study fills this gap in the literature by identifying the support strategies behind innovations that are widely adopted.

Results

Interviews with the developers of widely adopted innovations in undergraduate STEM are the primary source of data. Documents such as publications and informal innovation histories were collected for each innovation to provide triangulation and enhanced contextual understanding. Interviews and documents were analyzed using the constant comparative method. Across cases, support activities were highly interactive, with personal communication. All project teams responded directly to individual questions from potential adopters. The other four main support activities were visiting and consulting, creating an instructor’s guide, offering professional development, and making it clear that support is available. Projects struggled to sustain support activities. Sustaining these activities involved creating a community of users and finding additional funding for the project.
Conclusions

The developers of widely-adopted innovations offer support to potential adopters, including personally answering questions. The presence of a community both led to the propagation of the innovation and meeting of support needs, as adopters could access a network of users and interact with them directly. Many projects struggled with identifying funding sources beyond initial development and dissemination grants. Some solutions included establishing a non-profit or commercial entity and establishing revenue streams of sales or donations from publishers and other commercial interests. Education developers should be sure to strongly consider using all five of the strategies used by successful projects. Developers should also think about what type of community would best suit their project and develop plans to create such a community.

Introduction

Efforts to improve teaching in science, technology, engineering, and mathematics (STEM) courses at large have led to the development of many innovative instructional strategies and materials. Some of them, such as Peer Instruction (Mazur, 1996) or Process-oriented guided inquiry learning (POGIL) (Moog & Spencer, 2008) have been implemented by thousands of instructors, leading to better learning outcomes for students in transformed courses. However, for every successfully propagated innovation, dozens of others are never used by instructors at scale (Fox & Hackerman, 2003; National Research Council, 2012). Much attention has been given to the problem of dissemination in STEM education, with research aimed at describing what successful dissemination looks like (e.g., Bourrie, Cegielski, Jones-Farmer, & Sankar, 2014; Hazen, Wu, Sankar, & Jones-Farmer, 2012) and how to plan for successful dissemination (e.g., Hinton, Gannaway, Berry, & Moore, 2011; Litzinger et al., 2011). However, while instructors and departments are generally aware of education research literature and innovative teaching strategies, this awareness does not translate into use, as promising educational materials are regularly tried and discontinued (Borrego et al., 2010; Henderson, Dancy, et al., 2012). Practices to raise awareness are working; the challenge now is making the leap from widespread awareness to widespread adoption.
The successful spread of educational innovations is commonly thought of in terms of the *dissemination paradigm*. This paradigm carries an implicit assumption that if instructors are made aware of an innovation and the evidence to support its efficacy, they will use it (Hutchinson & Huberman, 1994; Froyd et al., 2017). To put more explicit emphasis on the goal of adoption, we introduce the idea of the *propagation paradigm* to describe the process of not only raising awareness of an innovation but actively engaging with potential adopters to support their implementation (Froyd et al., 2017). This means planning for support activities in addition to dissemination activities. However, developers of education projects often have a limited repertoire of dissemination activities, and support activities are rarely considered (Stanford et al., 2017).

To address the issue of lack of uptake, support activities are a critical aspect of the propagation paradigm, as instructors benefit from supports such as coaching and feedback (Austin, 2011; Clark, Froyd, Merton, & Richardson, 2004; Henderson et al., 2011). Beyond a few hints in the literature that support is helpful, however, support activities are generally not well-understood, and difficult for even experienced developers to provide (Khatri et al., 2016). This study delves into the question of how developers can plan to support instructors in their efforts to implement new teaching strategies and materials in their classrooms through an analysis of successfully adopted STEM education innovations.

**Literature Review**

Two areas of literature inform this study: current support practices within STEM education, and factors in the literature thought to impact support.

Current Support Practices in STEM Education

A study analyzing the propagation practices outlined in 2009 NSF proposals found that while some support activities do exist, most projects do not have plans for support (Stanford et al., 2017). Activities mentioned in grant proposals included providing example materials to other instructors who are interested in the innovation, and thinking about making the new instructional materials modular or flexible to make it easier for other people to adopt.

Less than 15% of the proposals in the year 2009 study considered follow-up with potential adopters (Stanford et al., 2017). The principal investigators (PIs) who had follow-up or
tracking mechanisms also had insight into the supports that adopters needed, while PIs without follow-up methods did not. An implication here is that establishing a method of following up and/or tracking adopters can help in creating support mechanisms.

PIs also struggle to locate funding for support activities, either applying for new grants, finding money from other sources, or moving onto other projects and discontinuing support (Stanford et al., 2017). Another concern is the question of how to structure support activities to be sustainable over the long term (Finkelstein & Pollock, 2005). Given the many known problems, it is important to learn about support activities that PIs can do, and how these activities can be carried out sustainably.

In previous case studies of three well propagated innovations, each of the project teams struggled with the question of how to provide support (Khatri et al., 2016). The innovations under study—Peer Instruction, Peer-Led Team Learning (PLTL), and the PhET Interactive Simulations—had different foci, but all discussed support activities (Table 4.1). In addition, a study of multiple implementation sites of SCALE-UP identified supports useful to implementers (Table 4.1). The other main support strategy seen in the literature is coaching and feedback (Henderson et al., 2011). This is repeated in implementation literature as well (Fixsen et al., 2005). The support activities identified in these studies are synthesized in Table 4.1.
Table 4.1 Support activities synthesized from a review of the literature

<table>
<thead>
<tr>
<th>Support Activity</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating additional ready-made materials for instructors</td>
<td>PLTL - created a guidebook for instructors with example problems (Leo Gafney &amp; Varma-Nelson, 2008) Peer Instruction- created the Peer Instruction User’s Manual (Khatri et al., 2016) PhET- created sample lessons using specific simulations (Khatri et al., 2016)</td>
</tr>
<tr>
<td>Mini-grant program</td>
<td>PLTL – Learned from adopters what the barriers were (financial resources and complicated implementation), and directly addressed them with a mini-grant program and direct assistance with implementation (Leo Gafney &amp; Varma-Nelson, 2008)</td>
</tr>
<tr>
<td>Direct Training and Site Visits</td>
<td>PLTL - directly helped implement, and encouraged successful sites to help neighboring institutions (Leo Gafney &amp; Varma-Nelson, 2008) Peer Instruction - hosted visiting researchers who wanted to learn it, and visited them later (Khatri et al., 2016) SCALE-UP – developer visited institutions, which sites found beneficial to their programs (Foote et al., 2016)</td>
</tr>
<tr>
<td>Maintaining the product over time</td>
<td>PhET had to keep up the simulations over time as technology changes (Khatri et al., 2016)</td>
</tr>
<tr>
<td>Making materials modular</td>
<td>Developers indicate they want to make materials that instructors can adopt piecemeal (Stanford et al., 2017)</td>
</tr>
<tr>
<td>Following up with adopters</td>
<td>Developers actively keep a list of users and communicate with them (Stanford et al., 2017)</td>
</tr>
<tr>
<td>Coaching and feedback</td>
<td>Observing, meeting frequently, and offering feedback (Fixsen et al., 2005; Henderson et al., 2011)</td>
</tr>
</tbody>
</table>

Despite this list of support activities, it is important to note is that PIs behind well-propagated innovations struggled to identify what supports to provide and in interviews indicated that some activities were unsuccessful, particularly fostering a community of users (Khatri et al., 2016). More work is needed to identify more support mechanisms, and the strategies behind them.
Factors in the Literature Relevant to Support

Rogers’ (2003) framework for the innovation-decision process describes the problem of lack of adoption in more detail. There are five stages in this process as adopters move from first learning about an innovation to the final decision to adopt it:

- **Knowledge**—Potential adopters become aware of the innovation and learn a little about it
- **Persuasion**—Potential adopters gain enough information to form an opinion (positive or negative) about the innovation
- **Decision**—Potential adopters choose to adopt or not adopt the innovation
- **Implementation**—Potential adopters try the innovation, putting it into place
- **Confirmation**—The adopter considers the decision to try the innovation and either continues or discontinues use

In studies to measure the extent of awareness and use of innovative instructional strategies and materials in STEM education using this framework, potential adopters are aware of innovations but often falter at the decision and implementation phases (Borrego et al., 2010; Henderson, Dancy, et al., 2012). Barriers discussed in these studies (and others) are largely local factors such as space necessary for student-centered pedagogy, instructor time commitments, concerns about necessary content coverage, and other resources that would be necessary to adopt innovative teaching strategies (e.g., Austin, 2011; Henderson & Dancy, 2007). These barriers factor into potential adopters’ decision to try the innovation.

Other problems arise as instructors implement the innovation, leading to discontinuation. Henderson et al. (2012) offer several reasons for discontinuation. First, the innovation was presented as easier to implement than it really is, leading to unrealistic expectations of how it would work. Second, instructors may not learn everything in detail about the innovation and make changes without realizing, leading to a lack of fidelity that could undermine the benefits of the innovation. Implementation literature suggests programs should be implemented with full fidelity before being adjusted (Fixsen et al., 2005). Third, support is lacking as instructors implement innovations, and coaching and feedback are known to lead to better implementation outcomes (Henderson et al., 2011). The takeaway from this research is that supports should...
specifically address the pain points in the innovation-decision stages of decision and implementation that are heavily influenced by aspects of the instructional system.

There are many factors in the instructional system affecting decisions to adopt and potential issues during implementation. An excellent framework for understanding the complexities of the instructional system with adoption of innovations in mind is by Lattuca and Stark (2009, 2011), which can be summarized briefly as thinking about the instructional system in four parts: individual, department, institution, and extra-institutional factors, each interacting in various ways with factors affecting them. For example, disciplinary differences can impact individual instructor decisions as teaching strategies align with or go against disciplinary norms—and some disciplines might support change while others (such as chemistry) are less supportive (Lund & Stains, 2015).

These instructional system factors and other change literature regarding attributes of innovations themselves are synthesized in the Designing for Sustained Adoption Assessment Instrument (Stanford et al., 2016). This instrument is intended to characterize proposals for education research innovations for what overall type of innovation it is, and has other sections devoted to evaluating the robustness of a proposal’s propagation plan. The portion of the instrument of relevance here characterizes innovations on factors that are thought to impact adoption, particularly the type of change: whether it is primarily a change in pedagogy, content, both, or no substantive change in either. Innovations that are not a change to either content or pedagogy tend to be either outside of the classroom or a change to make existing instructional activities more efficient, such as online homework to supplement/replace written homework. Analysis of well-propagated instructional strategies and materials using these categories suggests innovations that are pedagogy changes and NSC are perhaps easier to propagate than content-changing innovations (Khatri et al., 2017). This makes the type of change an attribute to consider in this study, along with the discipline in which the innovation originated.

Research Questions

The literature indicates that support activities are helpful to promote adoption of educational innovations, but they are usually not planned for initially in projects, nor are plans to identify support needs.
The broad research question guiding this study is: How do developers of successfully propagated innovations support their adopters?

More specific questions that this study addresses are: What support activities can developers provide during initial implementation? How do they sustain these support activities? How do developers find out about support needs? And are there differences in support needed for innovations based on their discipline or the type of change they represent?

Methodology

Data Collection

Selecting cases for this study was first a process of finding which innovations in STEM education are well-propagated. The process is addressed in more detail in another article (Khatri et al., 2017). To summarize, experts in each discipline of STEM education (identified from national report authorship, leadership in professional societies, and professional networks of the project team and advisory board) were asked in an email survey to list innovations they believed to have been widely adopted in their discipline in the past 10-15 years. This list was member checked, validated with input from an additional 70 experts in a workshop, and checked individually for evidence of propagation in web presence and the literature. Descriptions of each innovation were written, and the project team categorized each innovation as being primarily aimed at changing pedagogy, changing content, changing both, or no substantive change in either. Additional information about this categorization scheme can be found elsewhere (Stanford et al., 2016).

From that list of innovations, the criterion to be included in this study was they had to be “branded,” that is, have a clear central project team or individual developer. Other innovations were too general to be studied discretely, such as “active learning” or “cooperative learning.” Twenty from that list were branded, and three have already been studied in detail in prior work (Khatri et al., 2016). This left 17 potential cases for study.

Lead developers were identified through grant information and project websites, along with their email addresses. All 17 were contacted, and developers from 11 responded. In two cases, the contacted developer recommended another person to talk to about the innovation,
leading to 13 total participants. The cases are from six different disciplines, and represent three different types of change. The 11 cases in this study are listed in Table 4.2.

Table 4.2 List 11 of cases in this study, adapted from Khatri et al., 2017

<table>
<thead>
<tr>
<th>Innovation name</th>
<th>Summary</th>
<th>Type of Change</th>
<th>Originating Discipline, other disciplines</th>
</tr>
</thead>
</table>
| Alice            | *Intro programming environment for object-oriented programming  
• Students drag and drop commands from a nested menu rather than typing out each line. This changes the focus from typing to major concepts.  
• Students can use premade characters and backgrounds, plus drag-and-drop commands to quickly write animation programs for the characters.  
• The Alice team has developed teaching materials, and there are also many textbooks penned by others for courses structured around this environment. | Pedagogy and content change    | Computer science                      |
| BlueJ            | *Intro programming environment based in objects-first teaching, intended for introductory Java instruction  
• The interface differs significantly from other Java environments such as Eclipse, offering a variety of visualization and interaction tools useful for learning and teaching.  
• Comes with a textbook focused on fundamental object-oriented programming principles taught through interactive objects-first experimentation – students can learn using objects straightaway. This is a pedagogical departure from traditional approaches to teaching Java.  
• Developed by M. Kolling. | Pedagogy and content change    | Computer science                      |
<p>| CATME Team Tools | *Online tool that allows instructors to form groups of students using default or instructor-defined data surveyed from the students. | No change in pedagogy            | Engineering, Management                  |</p>
<table>
<thead>
<tr>
<th>Innovation name</th>
<th>Summary</th>
</tr>
</thead>
</table>
| *Instructors can also collect self- and peer-evaluation data on team-member effectiveness according to a scientific model.  
*The system provides diagnostic information to the instructor about teams that may require intervention.  
*Developed by M. Ohland and M. Laughry. |
| Geogebra | *Interactive software that joins geometry with algebra and calculus: rather than just showing and manipulating shapes, shapes are linked with algebraic expressions and spreadsheets in different views  
*There is an active online community of educators sharing activities and tutorials. Geogebra learning centers around the world offer resources and assistance.  
*Instructors can integrate the software into their course according to their own circumstances.  
*Free to use.  
*Developed by M. Hohenwarter. |
| Just in Time Teaching | * Refocuses lecture-based classes to be more active.  
* Students complete textbook reading (or perhaps watch a video) and answer questions on the concept covered before coming to class (often called “warmup exercises,” “preflight checks,” or “checkpoints”).  
* Instructors review the responses before class and tailor the lecture and activities to areas of student difficulty.  
* Instructors typically use JiTT with a web-based course management system or other communications system and can develop their own activities or use activities already developed by instructors in several disciplines. |

<table>
<thead>
<tr>
<th>Type of Change</th>
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<tr>
<td>or content</td>
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<tr>
<th>Originating Discipline, other disciplines</th>
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<tr>
<td>Pedagogy and content change</td>
</tr>
<tr>
<td>Math</td>
</tr>
<tr>
<td>Physics</td>
</tr>
<tr>
<td>Innovation name</td>
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</table>
| **JiTT and Peer Instruction**   | • JiTT and Peer Instruction are often used in combination.  
  • Developed by G. Novak, E. Patterson, A. Gavrin, and W. Christian.                                                                                                                                    |                                    |                                            |
| **Learning Assistants**          | *Undergraduate students are hired to facilitate small-group interaction in large-enrollment undergraduate courses  
  • This can occur either during whole-class sessions or in recitation sessions.  
  • Learning assistants are given training in leading group discussion and meet regularly with the course instructor.  
  • Originally developed by V. Otero.                                                                                                      | Pedagogy change                    | Physics                                   |
| **LON-CAPA**                    | *Web-based homework system gives students feedback on their responses based upon common mistakes and misconceptions  
  • Each student is given a slightly different version of the homework set to discourage cheating.  
  • The instructor selects (or creates) questions and determines how many attempts a student may make.  
  • LON-CAPA requires a server at the institution and is installable only using Linux, although it is viewable by most operating systems.  
  • Originally developed by G. Kortemeyer et al. at Michigan State University.                                                          | No change in pedagogy or content    | Physics                                   |
| **Process Oriented Guided Inquiry Learning** | *Instructional format where students work in self-managed teams on inquiry-type activities  
  • Activities are written in a specific manner, and the instructor can write their own if they desire and submit it for review.  
  • Instructors using POGIL do not use a traditional lecture format but instead provide guidance and facilitate student activities.  
  • POGIL has been adapted to work                                                                                                           | Pedagogy change                    | Chemistry, Biology                       |
<table>
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<tr>
<th>Innovation name</th>
<th>Summary</th>
<th>Type of Change</th>
<th>Originating Discipline, other disciplines</th>
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</table>
| SCALE-UP      | *Instructional format where students work in small cooperative groups on activities, many of which are hands-on.  
• Suggested classroom design includes round tables and computers for each group, but neither of these features are essential.  
• Instructors move throughout the room, offering guidance but not lecturing more than a few minutes.  
• When implemented with the suggested classroom setup, requires a custom institutional space and significant technology.  
• Originally developed by R. Beichner. | Pedagogy change | Physics, Biology |
| WebWork       | *Open-source online homework system for undergraduate math courses  
• Instructors build homework sets from the large available database, can set the number of attempts per problem, and can use the system to record homework grades.  
• Students can instantly see if their answer is correct.  
• There is an online community of users.  
• WebWork requires a server at the institution, or the department can pay another host. Based upon the code for LON-CAPA. | No change in pedagogy or content | Math |
| Workshop Physics | *Instructional format in which traditional lectures and weekly laboratory sessions in a calculus-based introductory physics are replaced with inquiry-oriented activities and occasional demonstrations.  
• Students are asked to make predictions about how a physical system will behave and verify their predictions via observations and experiments. | Pedagogy change | Physics |
Table 4.2—Continued

<table>
<thead>
<tr>
<th>Innovation name</th>
<th>Summary</th>
<th>Type of Change</th>
<th>Originating Discipline, other disciplines</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>• Classes normally meet for three 2-hour long guided inquiry sessions each week where students work in groups of three or four to test their predictions. The activities are outlined in a series of four workbooks entitled “The Workshop Physics Activity Guide.”</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Developed by P. Laws et al. at Dickinson College.</td>
<td></td>
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</table>

Documents about each innovation were collected to establish an understanding of the innovations themselves and their history. In many cases, the developers had written a history of their innovation (formally in an article or informally), which was available on their website or provided over email. In some cases, developers sent relevant publications pertaining to their innovation. Semi-structured telephone interviews with the developers were conducted. The main questions remained the same for all interviews and focused on the respondent’s perceptions of what support was available to users or potential users of the innovation (see appendix for interview protocol). Questions pertaining to specific innovations were also included based on document analysis.

Data Analysis

Documents were read and notes were taken on salient points prior to each interview. The interviews were transcribed and analyzed as soon as possible after they were conducted, using open coding to capture all possible actions described in the interviews, particularly generating a list of support strategies. Short case descriptions were developed, determining a sequence of common events for easy comparison across innovations. Relationships among the codes and categories were probed through code co-occurrence analysis and the use of conceptually ordered displays (Miles & Huberman, 1994). These drew upon constructs identified in the literature as potentially relevant to supporting adopters; for example, the type of innovation, originating
discipline, and stage of implementation. This process led to the development of themes, which are reported below.

Results

The results are reported in three parts: 1) commonly-used support activities, 2) the importance of community in providing support, and 3) the importance of continued funding in providing support. Figure 4.1 summarizes how the themes relate to the activities and to each other.

![Diagram showing the relationship between support activities, community, and funding.]

Figure 4.1 Summary: Support activities are sustained through user community and funding

Commonly-used Support Activities

Table 4.3 Support activities undertaken by developers in the study

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Usage (out of 11 innovations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Providing community</td>
<td>Facilitating community within the user base, providing virtual support (e.g., forums, wikis, list-servs), and/or in-person support (e.g., dedicated conferences, workshops)</td>
<td>6</td>
</tr>
</tbody>
</table>
Table 4.3—Continued

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Usage (out of 11 innovations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecting users to each other</td>
<td>Introducing users to each other to provide support (outside the community setting)</td>
<td>8</td>
</tr>
<tr>
<td>Responding to individual problems</td>
<td>Responding to emails and phone calls from adopters</td>
<td>11</td>
</tr>
<tr>
<td>Visiting and Consulting</td>
<td>Visiting institutions implementing the innovation. Speaking with deans and department chairs to help faculty pitch the innovation is often involved.</td>
<td>9</td>
</tr>
<tr>
<td>Writing an instructor’s guide</td>
<td>Providing written guidance on how to implement an innovation, often with example problems</td>
<td>9</td>
</tr>
<tr>
<td>Making it explicit there is support available</td>
<td>Prominently featuring support in materials/conversations, such as having clear links on project webpages and being informally available</td>
<td>9</td>
</tr>
<tr>
<td>Policy Assistance</td>
<td>Helping adopters create a favorable climate for adoption among key local stakeholders and alter local policy/make the innovation fit local policy (often part of site visits, but done remotely too)</td>
<td>5</td>
</tr>
<tr>
<td>Frequently Asked Questions</td>
<td>Having a short list of FAQs on the project website and/or short informational videos</td>
<td>9</td>
</tr>
<tr>
<td>Professional Development</td>
<td>Providing workshops with more detail beyond introductory level, targeting specific problems developers are aware users encounter</td>
<td>10</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Conforming to ADA requirements and translating into new languages</td>
<td>4</td>
</tr>
<tr>
<td>Instructional videos/tutorials</td>
<td>Providing videos or written tutorials to assist with successful implementation (distinct from instructor’s guide)</td>
<td>6</td>
</tr>
<tr>
<td>Technical Support</td>
<td>Specific to innovations with a technology component, this includes installation and hosting support, bug fixes, custom support for new features, and a dynamic feedback system (mostly for student users)</td>
<td>6</td>
</tr>
<tr>
<td>Maintaining the product over time</td>
<td>Keeping the product up to date. This is mostly a software/technology issue, but pedagogical innovations also need to update materials over time, such as the instructor’s guide</td>
<td>9</td>
</tr>
<tr>
<td>Keeping a list of users</td>
<td>Keeping track of users through the use of a community mechanism, personal database, or wiki</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 4.3 lists the support activities used by the innovations in this study. Several support activities were seen across all or nearly all of the innovations:

- Visiting and consulting
- Instructor’s guide
- Professional development
- Making it explicit that support is available
- Responding to individual questions

These five activities, or VIPER (Visiting/consulting, Instructor’s guide, Professional development, making it Explicit support is available, and Responding to individual questions) are discussed in detail below.

Visiting and Consulting

Developers go in-person or offer virtual consulting to help adopters with program installation and initial implementation. It was noted in interviews that this was particularly effective for helping people grasp the innovation and directly put it into place at their sites. Visits have a few functions: providing training to individual faculty at the institution, as well as helping instructors discuss the innovation with local decision-makers such as the chair, dean, or provost. In some cases, it can be the other way around, with a department chair trying to demonstrate the value of the innovation to the faculty.

A variation on visits is having adopters come to the developers or other users of the innovation:

“Once we got the grant we had money so that we could bring people to watch us, or other people who were implementing, actually implement the materials in the classroom. People could come to my classroom and watch my class, and they would say, ‘Yeah, this is ... Now I understand much better what I’m supposed to be doing in class or how this is supposed to work.’” (POGIL)."
Site visits are of course time-intensive, and one solution to this is offloading visits from the original developers to adopters who have implemented the innovation themselves.

“I kept getting invited to give sessions all over the nation, like hi, can you come to Auburn, can you come to Atlanta. It's very far away for me to travel that far, and yet, I know there's somebody in Florida, somebody nearby that's running an excellent LA program that could actually travel less and provide the same or different, but equally valuable consulting with these universities that were inviting me out.” (Learning Assistants).

In the case of the Learning Assistants, the process of having an experienced user come help is now formalized within the “L-Agent” program. In other innovations, this process of connecting new and old users is less formal, and usually through the use of a central database maintained by the core developing team:

“We've turned to that database time and time again when we need to find out something like [...] is there anybody in Cincinnati who's using WebWork, because there might be something where we need to talk to somebody in that region to see if somebody could host for a school that's interested.” (WebWork).

While site visits are helpful to adopters, maintaining the database of users to direct others to and/or creating formalized structures within the user community require time and effort on behalf of the developers. Many site visits were funded by dissemination grants, and after the grant period, other ways to fund visits such as hiring visiting experts as consultants become necessary. Another way is tucking a visit within giving a departmental seminar: “People would invite me to give a colloquium talk and then, you know what, if I'm there anyway [I can help them implement LON-CAPA].” (LON-CAPA). Without financial assistance, visiting is logistically much more difficult.

Instructor’s Guide

Almost all the innovations in the study have a written guide to help instructors both gain more information and help with initial implementation. Developers discussed using the guide in a few different ways. One way is to overview problems users are likely to run into and how to address them: “[It’s] not just the lesson plan itself, there should be a part that the student doesn't see. That tells the teacher, ‘This is the kind of problem that we have typically seen students have with this and here's how we handle it.’” (Alice). Another use is to offer variations on
implementation, “so that people can get a vision of the different ways that LA’s are used on our campus.” (Learning Assistants). One developer pointed out the need for the materials be complete and well-researched, so teachers can confidently take them and use them immediately: “It needs high quality teaching material that teachers can take that tells them what to do.” (BlueJ).

While having ready-made materials may sound simple, finding resources to write it and especially maintaining it over time were issues that many developers encountered. As one developer put it, “There’s, of course, there’s no research in providing the support materials.” (BlueJ). Initial funding for all these innovations came from grants, and while research publications are an expected product of grant funding, additional support materials are not. As a consequence, developers often spent their personal time to write supporting materials, and even with current funding, struggle to keep up with developments and produce new content.

Professional Development

Developers discussed workshops and professional development opportunities to aid adopters in learning more and in their initial implementation. This professional development goes beyond short introductory workshops or presentations and targets specific issues that instructors have with the innovation, from understanding the innovation more deeply to developing confidence in using it in the classroom. In the case of Alice, the developers attended regional conferences, presented the innovation, and specifically set aside time at the end of talks to ask what would stop instructors from using it. From these conversations, the team “realized that we needed to do something to help [instructors] feel confident about their skills.” These potential barriers were addressed in the workshops they ran as part of a national dissemination grant.

“…we didn't get the grants to do the workshop just because we wanted something to do. We were not doing it as a promotion. We were doing it because of what we had learned at the regional conferences in talking with the professors.” (Alice)

Making it Explicit Support is Available

Developers made it clear that personal support was available through prominent links on project webpages, making their email available, and indicating in conversations with potential
adopters that they were willing to field questions. Developers talked about the importance of making it clear that support is available immediately, mentioning their turnaround time for being able to answer questions: “We provide technical support. So we have a support email address and we answer every email within 24 hours. We provide quite detailed technical support if people have problems.” (BlueJ). One strategy to indicate support is available fast was to have several avenues for help listed and point out the fastest one:

“If you need an answer quickly or think that other teachers are your best bet then join our teacher listserv and ask them yourself. We have an active group that responds very quickly to requests for help. We also love for people to join this group and share their work, upcoming events, and things they think will be helpful directly to our community.” (Alice website)

Responding to Individual Questions

All the developers discussed taking the time to respond to individual questions from instructors about specific problems, primarily as adopters were initially implementing the innovation. This could be following up from conversations at conferences:

“You could kind of tell during those sessions who would be the most likely folks to actually go ahead and try using it, because they'd come and ask us a whole bunch of questions after a session was over. They would email us, they'd call us, they'd come meet with us at another meeting conference or something that occurred. This was all pretty informal.” (WebWork).

Responding to adopters in this personal manner is also a part of the overall support and propagation strategy for some developers:

“I just assume that if somebody is going to be disseminating some new pedagogy or some new approach, that they are prepared, whoever the leadership is, to receive emails and phone calls from people who have questions about what they're supposed to be doing, and that they will respond to them. Clearly, if you don't do that, you're going nowhere.” (POGIL)

It is often from these individual conversations that developers realize the need for other support mechanisms, such as having an instructor’s guide and an FAQ.
Commonly-used Support Activities Summary

Five support activities—visiting/consulting, instructor’s guide, professional development, making it explicit support is available, and responding to individual questions (VIPER)—are used by nearly all of the innovations in the study. Developers make it clear that support is available, and tailor support activities to known problems that adopters are likely to encounter. In some cases, developers actively seek feedback on potential barriers to adoption, but most in this study realized the need for support mechanisms more organically, often through the many one-on-one conversations with adopters.

Previous research indicated that developers need to actively seek out what kinds of supports adopters need (Stanford et al., 2017). The cases in this study usually did not deliberately identify needs in a systematic manner, but more commonly developed supports to address common questions and issues that adopters approached them with. In several cases, a common theme was that an overwhelming number of support requests made of the lead developer(s) necessitated that the developers find ways of offloading some of the support activities. Solutions included having an instructor’s guide, FAQs, and leveraging the community of users to offer support.

Supports by Innovation Type

Aside from the five main support activities used by all the innovations, cases were compared by discipline and innovation type. While there did not appear to be any differences by discipline, there are specific differences in activities by type of innovation, because the supports are motivated by unique needs. The three types are innovations with no substantive changes to pedagogy or content, changes in pedagogy, and changes in content.

Supports used by Innovations with no Changes to Content or Pedagogy

These innovations ((WebWork, LON-CAPA, CATME Team Tools) offload many questions to FAQs and instructional videos/tutorials. In two cases, a dynamic feedback system was developed for students using the innovation:

“They made a video, which has helped a lot because if a student tries to log in and they mess up, I think if they mess up twice in a row, it actually pops up a link and says, "You need to watch a video on how to log into the
That has saved us, probably, a lot of questions, as well as provided immediate feedback to those students on what to do.” (CATME Team Tools.)

Innovations in this group also design for usability up front so adopters will need less support:

“So it was designed from the beginning to be something that lots of people could use. It's very far from perfect, but there's still a lot, in terms of the software and so on, that not only that it works for me and on my machine, that's when you're 60% of the way towards getting something that's really usable across the country. There's a lot of work that goes in after that to make sure that it actually works on other people's machines; and that it's the sweet spot between being too complicated to learn and too rigid to be useful.” (WebWork)

Compared to the other categories, there is less of a community in two out of the three innovations that fall into this category, and the motivation to provide support is more technical in nature rather than personal.

Supports Used by Innovations Representing Change in Pedagogy

This group (POGIL, Learning Assistants, SCALE-UP, Workshop Physics, Just in Time Teaching) visits/consults more than the other two groups, providing both training in the innovation and often providing policy assistance by discussing the innovation with local stakeholders:

“[…] if I was talking to a department chair or a dean, it usually was because there was somebody in the department who was really interested in doing this, and so a little bit groundwork had been laid, but people just needed assurance that this wasn't going to damage their students. That's sort of what they were concerned about.” (POGIL)

While two of the five studied had a community around the innovation, three did not—while many people use it, they do not always form a community. Another difference is the other groups of innovations both have instructional videos and/or tutorials on use of the innovation, and this group does not have any at all—while the other groups contain more technology innovations and therefore video tutorials are more the norm, video tutorials are another potential support activity this group could consider.
Supports Used by Innovations Representing a Change in Content and Pedagogy

These innovations (GeoGebra, Alice, BlueJ) all involve technology and thus provide technical supports to adopters, but two out of the three also have strong professional development support in place to assist adopters in their confidence level using the innovation (GeoGebra and Alice.) In the case of GeoGebra, “…teachers need lots of confidence with technology. I think just giving them some kind of, going through the materials and working with them. I think that is the best way, to have more like personal attention and so on.” This is similar to Alice:

“99 out of 100 of them had no experience with animation and so, to think you’re going to walk into the classroom and teach using an animation tool is pretty close to suicide, right? Professionally. So, in order to get them to change their ways, we had to ... We realized that we needed to do something to help them feel confident about their skills.”

The Alice team ran weeklong workshops to train instructors in the use of Alice and teaching with it, and made it clear additional support would be available during implementation to build this confidence.

Support Activities by Type of Innovation Summary

Three broad types of innovations were included in this study: innovations primarily focused on changing pedagogy, innovations with both a change in pedagogy and a change in content, and innovations with no substantive change in either. The no change in content or pedagogy group, being technological in nature, provided technical support such as bug fixes and installation support. In addition, they offloaded support needs by designing for usability up front and having dynamic feedback systems. The innovations changing pedagogy frequently visited and consulted with adopters, often using those visits to both train adopters and provide policy assistance by speaking with stakeholders. Finally, the innovations to change both content and pedagogy displayed the most supports specifically targeted toward increasing adopters’ confidence in using the innovation.
Sustaining Support Activities

This section of the results details the two themes relating to sustaining support activities: community and funding.

Community

Most of the innovations had some kind of organized user base, forming communities around the innovation. These communities contributed to sustaining support activities, in many cases directly providing assistance to other adopters and contributing teaching materials; and in some cases running events such as conferences and workshops.

It was quickly clear in the analysis that the communities all had a varying “sense of aliveness” (Wenger, Mcdermott, & Snyder, 2002). The level of community activity varied considerably between cases, and is not particularly correlated with number of total users. Common features of community in each of the three activity levels—highly active, moderately active, and no community—are reported below.

i. Highly active communities

These communities (Learning Assistants, POGIL, GeoGebra) are large (thousands or in the case of GeoGebra, millions of users) and members often actively contribute in some way to the innovation itself: for example, through creating materials, research, hosting conferences, and workshops. These communities offer support to other users, and in many cases users can directly contribute materials. These communities provide leadership development for adopters, offering advanced training in how to host conferences and run workshops, and providing opportunities for taking on leadership roles.

Some are centrally organized through the lead developer’s websites, and others are more de-centralized through regional headquarters. In two of the cases, POGIL and GeoGebra, a non-profit has been established as the home of the community. In addition, these highly-active communities have created a new structure for the community itself that is separate from the innovation. It is appropriate to consider the three highly-active communities as communities of practice as they are organized around common knowledge domains and developing shared practice (Allee, 2000; Wenger et al., 2002). There are events in-person and from a distance; in
the literature, this is referred to as a “distributed” community of practice (Kezar & Gehrke, 2015).

GeoGebra has the largest community, and it is managed through a non-profit.

“We have a global community of teachers and students, which we support through our not for profit organization, and there are many many millions of those people that are part of that group in excess of 30 million, we had over 70 million unique starts of the software that we could measure last year.” (GeoGebra)

The GeoGebra community is structured into hundreds of international GeoGebra institutes, which serve regional needs and host local conferences and workshops.

“Then it was growing very quickly so people sharing lots of ideas. And they wanted to involve both in the development and also in the community to help to each other. People are organizing conferences and so on.” (GeoGebra)

The Learning Assistant Model developed the Learning Assistant Alliance as a way to support adopters around the world.

“By 2010, we were getting people coming to the conference from Japan, Singapore, India, Ireland. We started to realize that it was an international event, and we needed a way to support people nationally as well as internationally. We need an alliance. We needed some coalescing of people who knew what they were doing to help other people.” (Learning Assistants)

There are formal structures for community members to take on leadership roles and contribute to conferences and workshops.

“In order to become a regional workshop runner, A), you have to be an L-Agent, and you also have to come for training, and the way they train is they run the international conference in the fall before their spring or summer regional workshop. So now, we don't even have to run the entire conference, which is too big for any two people to run.” (Learning Assistants)

There is also an avenue to decentralize leadership, by having an elected steering committee, a feature shared with POGIL.

POGIL, like GeoGebra and Learning Assistants, developed a separate part of the project for the community element. There is the POGIL pedagogy and the separate POGIL Project.
“POGIL is a pedagogy…the POGIL Project is a professional development organization. Although those two things are closely related to each other, they're actually different things.” (POGIL)

Similar to Learning Assistants, there are formal structures for community members to take on new leadership roles, which is part of the overall strategy to sustain the POGIL Project. “The other key thing that I think we did and that I think is really important, is that from the beginning be thinking about, how are we building additional experts, leaders, disseminators? How are we building them, how are we training them, how are they getting pulled into the fold, how are we developing these leaders, so that when we are successful, we, meaning the originators, don't have to do everything, because we won't be able to.” (POGIL)

ii. Moderately active communities

These communities (WebWork, BlueJ, Alice) can also be large (thousands of users) but the visible number of active users is smaller (in the hundreds.) These communities are organized mostly online, through forums and list-servs, and members may contribute materials they have created, or troubleshoot issues for other users on the forums. Adopters may have participated in events in the past taking part in development of the innovation itself, but these events are infrequent or no longer happening regularly. For example, WebWork, which is an open-source community, has held in-person events which involved users in the development of the software itself:

“We would have workshops on a regular basis, two or three a year, which would bring 20 or 30 people together there. They were originally meant to be outreach workshops, but our goal for the dissemination project was to reach 450 schools, and we'd done that by year two of a five year grant. So we repurposed a bunch of that into more training people to author problems, to edit problems, to help with the software; help develop the core software of WebWork, and get people kind of more involved in the community.” (WebWork)

The WebWork team indicated that the in-person workshops were a useful tool for cultivating community, and expressed a desire to continue the workshops. Their grant funding has ended and they are seeking avenues for funding and structure, considering a non-profit. Considering literature on the life cycle of a community, it may be that WebWork is at the beginning of coalescing, and is headed toward being a highly active community (Kezar & Gehrke, 2015).
iii. No community

In these cases, (SCALE UP, Workshop Physics, JiTT, CATME Team Tools, LON-CAPA) the project is entirely centralized around the lead developer, with little to no organic interactions between adopters. Adopters might take on major roles such as doing research on the innovation and helping local institutions implement their own program, but there is no structure for connecting without approaching the original developer. For example, a social network analysis of SCALE-UP spread found that the network is highly centralized around the lead developer, with few ties between other individuals (Neumeyer, Foote, Beichner, Dancy, & Henderson, 2014).

v. Community summary

Three levels of community activity were noted across cases, described here as highly active, moderately active, and no community. Highly active communities have created new structures to facilitate the community itself, and have found ways to cultivate leadership in community members. These communities are active in supporting users and contributing to development of the innovation itself. Moderately active communities support users mostly in virtual modes, with occasional in-person events. Users contribute materials and share experiences with others over online mechanisms. Finally, innovations with no community have active users but they do not interact as a community. Adopters of these innovations might be very active with research on the innovation or helping local institutions adopt it, but these connections are entirely facilitated by the central project leadership. It is important to note that there does not seem to be a correlation between community activity level and number of adopters, but the innovations with a strong community component are thinking strategically about sustaining the innovation itself over the long term.

Funding

In nearly all cases, the innovation began with grant funding (or initially piloted without funding but funded later) and during the funded years undertook education research and development of the innovation. At the time of this study, in many cases, the central project was done with the main development of the innovation and now focused more effort toward
supporting users instead of research or development. Continuing project activities is now primarily a question of continuing support activities.

In this study, most of the innovations have stabilized sources of funding to continue activities. One strategy mentioned by several of the innovations was creating a new financial structure to continue project activities through a revenue model, either commercial or non-profit. The rest of the innovations continue as academic projects housed by their originating institution, headed by the originating project team.

Three of the innovations created new entities to manage funding. POGIL created a 501(c) non-profit. Money from donations, grants, sales from publications, and charging for workshops is managed through the non-profit model. GeoGebra created both a commercial entity and an international non-profit. The commercial entity manages commercial licensing agreements with corporations, governments, any commercial interest that wishes to use GeoGebra for commercial purposes. The commercial side supports activities of the non-profit side, and allows for continuing to develop software with a staff of roughly 30 people. CATME Team Tools became a non-profit center within Purdue. There are licensing options for individual use and for institutions to use CATME, and this is organized through the non-profit.

Two of the innovations studied were currently in transition points where additional money is needed for project activities, and were looking for models to do this.

WebWork was at the end of a national dissemination grant, and looking to start a non-profit. The project needed funding to continue in-person workshops to continue building the community.

LON-CAPA is currently maintained through funded by the developing institution, but more funds are needed to upgrade the technology to keep up with current web protocols. In the past, LON-CAPA has tried to start a commercial entity to charge for the service, but this was unsuccessful.

i. Funding summary

Securing additional funding for support activities was a challenge for all of the projects. Most have continued through institutional funding at the originating institution. Some have developed financial structure with alternate revenue streams to continue project activities, and others are trying to locate alternate funding.
Discussion and Implications

This study investigated the questions: How do developers of successfully propagated innovations support their adopters? What support activities can developers provide during initial implementation? How do developers find out about support needs? Are there differences in support needed for innovations based on their discipline or the type of change they represent? How do they sustain these support activities? Analysis of eleven innovations in STEM education that have been successfully implemented by hundreds or thousands of instructors led to the following findings.

What Support Activities can Developers Provide During Initial Implementation?

Almost all of the innovations, regardless of discipline or focus of the innovation, used the following support mechanisms to assist adopters during their initial implementation, which can be remembered with the acronym VIPER: visiting/consulting, instructor’s guide (often with ready-made materials), professional development (often intensive, multi-day experiences), making it explicit support is available, and responding to individual questions. This is in contrast to typical developers of educational innovations who rarely plan for support activities. For example, a web search of funded development projects found almost no interactive support mechanisms (Stanford et al., 2017). Further, the successful developers in this study make it clear that support is available to adopters. In the business literature, the successful launch of new products is linked to marketing materials emphasizing that support is available (Goffin & New, 2001; Lele & Karmarkar, 1983). Similarly, in STEM education, it appears that making it clear to potential adopters that there is help in implementing new teaching strategies and materials may be linked to successful adoption.

How do Developers Find Out about Support Needs?

Prior research indicated that developers should actively seek out supports needed by adopters (Stanford et al., 2017). Through frequent one-on-one interaction with adopters, developers in this study learned of common issues and created mechanisms to address them. While projects usually did not set aside specific time to research and develop support needs, they did devote extensive time to adopter questions.
Are there Differences in Support Needed for Innovations Based on their Discipline or the Type of Change they Represent?

The innovations in this study originated in a variety of STEM disciplines; however, the discipline did not affect support mechanisms. The type of change to teaching practice the innovation represented, using the categories of a change in pedagogy, a change in both content and pedagogy, or no substantive change in either (Stanford et al., 2016; Khatri et al., 2017) determined support activities. The no change in content or pedagogy group was heavily technological in nature, meaning there was a need to provide supports such as software updates. The pedagogy-focused innovations often visited and consulted with adopters, providing training opportunities and addressing stakeholders in the department. Innovations that change both content and pedagogy created supports to increase adopters’ confidence in using the innovation, as these represented substantial change from typical teaching practices.

How do Developers Sustain These Support Activities?

One way to sustain support activities was to host a community around the innovation. The innovations in this study had varying levels of community associated with them. While all the innovations are widely adopted, and adopters often contribute to research and assisting other adopters in implementation, community does not automatically form around them. The innovations with highly active communities have continuing funding, either through a new revenue stream and/or continuing to apply for grant funding. They also provide opportunities for community members to take on leadership roles, which in turn means more support resources for new adopters. While not strictly necessary for supporting adopters or for widespread adoption, intentionally building a community (or at least tracking users) may be a strategy for developers of future innovations to consider; currently, developers of education projects rarely plan for providing infrastructure for a community (Stanford et al., 2017). Literature on communities of practice indicate that they cannot be forced; rather, they should be organic (Wenger et al., 2002). However, in STEM education, communities tend to be more intentionally started and structured (Kezar & Gehrke, 2015), and there are ways to cultivate an active community.

Finally, the problem of project funding to continue these activities was handled in a few different ways by the innovations in the study. One thing noted across interviews was the funding model of asking users (instructors) to pay was usually ineffective, as was seeking
additional grant funding after the innovation had been developed. Stated another way, “reluctance to keep a good thing going is built into NSF’s distribution of funds” (Seymour et al., 2011, p. 23). Projects either continued on by restructuring into a new entity (establishing a non-profit organization, establishing a commercial entity, or becoming a formal non-profit associated within the university) or by continuing through the university without a formal restructuring. Projects that found another funding source or sources were able to hire staff to continue project activities, which were heavily focused on support activities such as providing infrastructure for the community and updating materials. Projects without new sources of funding had difficulty keeping instructional guides and software up-to-date, and could not provide other supports without investing personal time. However, developers noted in interviews that creating new financial structures to house the innovation was often a difficult task they were ill-prepared for, as is finding a revenue stream, regardless of the legal structure that houses the finances. Recognizing the difficulty of funding innovations indefinitely through grants, there should be resources for developers to write a business plan to continue project activities.
CHAPTER V

CONCLUSION

In this chapter, the project as a whole will be discussed—a summary of the work, the overall contribution it makes to new knowledge, and an agenda for future work based upon the findings here.

Dissertation Summary

The overall goal of this dissertation project was to address a pressing issue in STEM education, the lack of adoption of educational innovations, by contributing to the knowledge base on strategies for developers of innovations to propagate their work. The hundreds of grant-funded education research projects that go unused by instructors represent millions of dollars wasted—while many of the projects no doubt added to DBER knowledge, the promised outcomes of changing STEM teaching at a broad scale remain unfulfilled. This is not the sole fault of researchers working on these projects, who do want other instructors to use the strategies and materials they develop, but instead is due to an opaque funding landscape for educational innovations that has for a long time collectively attributed successful propagation of the rare popular innovations to vague and mysterious factors: “it must be a good idea,” “the PI is very charismatic,” “the idea is ‘sticky’ for some reason.”

This dissertation was part of a larger multidisciplinary project to de-mystify the process of propagation (Henderson et al., 2015; Stanford et al., 2016; Stanford et al., 2017). Part of this larger project that is not described in the dissertation involved reading funded NSF Transforming Undergraduate Education in STEM (TUES) proposals. While the problem of propagation was initially abstract for a new graduate student on this project, being immersed in the problem in the most direct way, seeing what is funded and what researchers are planning to do to get others to use their work, brought me up to speed quickly. The same issues were apparent over and over again in proposals: PIs wrote in their broader impacts section that they would publish a paper, go
to conferences, and hold workshops. There would very often be no plan for communicating the results of the grant beyond those staple activities. Sometimes proposals neglected to mention even those activities. Clearly, those strategies are not transforming STEM education.

The goal, then, of the entire project and of my dissertation, was to research what strategies *do* work to propagate STEM education innovations. Being so unexplored, this meant qualitative research was needed, generating rich data directly from people close to the problem, including experienced developers of the innovations that had been successful in reaching a large audience. This dissertation project has been presented here in the form of three articles. The project began with identifying which innovations were well-propagated (article one), then conducting case studies of several of the well-propagated innovations (article two), and finally inquiring further into questions left over from the case studies with additional interviews with developers of well-propagated innovations (article three.) The three articles are summarized in the sections below.

Article One: Characteristics of Well-Propagated Teaching Innovations in Undergraduate STEM

This study explored the general landscape of what innovations are widely used in STEM education across disciplines, and some characteristics of these innovations. Soliciting the opinions of experts in STEM education, I asked in an email survey what teaching strategies and materials they believed had been widely propagated in their discipline. After member checking, validating, and seeking feedback from additional experts, I collected publically available funding information and created descriptions of each, sending these descriptions to be checked by the original developer when possible. Analysis included categorizing the innovations and looking for relationships between the variables of funding, discipline, level of specificity (whether it is a general movement such as “active learning,” something recognizable such as “think-pair-share,” or something branded such as “Peer Instruction”) and project type (whether it was a change in pedagogy, content, both pedagogy and content, or no substantive change in either). The main findings were the duration and amount of funding the innovations had over time, having all received at least a half million dollars and over a period of ten years. In addition, the changes that the innovations represented to teaching practice were mostly focused on pedagogical changes or no substantive change.
Article Two: Designing for Sustained Adoption: A Model of Developing Educational Innovations for Successful Propagation

The goal of this paper was to articulate a model of how to develop innovations for propagation, based upon several sources of data: open response survey data from NSF PIs, focus group data from NSF Program Directors (PDs), and case studies of three innovations that had been identified in the first paper as well-propagated: Peer-Led Team Learning, the PhET Interactive Simulations, and Peer Instruction. Grounded theory methodology was used, as it is useful for areas where little research has been conducted, for describing a process, and for pulling together many sources of data (Corbin & Strauss, 2014; Creswell, 2007; Gibson & Hartman, 2014). The open responses from PIs led to a description of their views on dissemination, and the focus group data from PDs led to insights on both typical propagation practice and successful practice, as they discussed both what they believed were strategies that were not working and drew upon their experience to describe innovations and activities that they believed were effective. Comparing the PI and PD views was the first step in building a model, collecting the many moving pieces in this complex problem into initial categories of activities, interactive development and interactive dissemination. Next, the case studies were conducted separately, each one compared with the others and compared with the model iteratively, testing assumptions, and then analyzed together, further testing and filling the categories in with concrete examples. The result was a model of propagation with four key components: interactive development, interactive dissemination, supporting adopters, and funding to continue activities at each stage. Development, dissemination, and support are all highly interactive processes, in which communication is two-way between adopters and the developers. Developers gain valuable feedback from adopters about the innovation and about their dissemination mechanisms, leading to a stronger product and dissemination strategies more targeted at specific barriers pointed out by adopters.

Article Three: Strategies that Support Sustained Implementation of New Instructional Strategies and Materials

This study was motivated by remaining questions from the second paper, namely the issue of support. It was the most uncertain category of activities from the study, without many examples of what it looked like, and without strong confidence from the developers in interviews
that their support mechanisms were helpful. The goal of the third paper was to address this hole, seeking additional support activities that developers can consider by interviewing the remaining developers from the list of innovations identified in the first article. Thirteen developers participated in the study representing eleven innovations, ranging across multiple STEM disciplines and types of change. Documents were collected and analyzed to establish familiarity with the innovation before talking with the developer, and to ask more specific questions for each innovation when applicable. Interviews were transcribed and analyzed as soon as possible after they were conducted, first in open coding and then for several themes. This process led to a list of support activities and the associated theme of sustaining support activities, through two vectors: community and additional funding. The main five support activities can be remembered with the acronym VIPER: visiting/consulting, instructor’s guide, professional development, explicitly clear that support is available, and responding to individual questions from adopters. Nearly all the innovations under study did these activities, and future developers should plan for these activities to help adopters during their implementation. Some of the innovations had very active communities, and this meant that potential adopters could access a network of experienced users for questions and help. The issue of how to continue funding project activities was addressed with varying degrees of success by the eleven innovations, with some of them unable to find a revenue stream despite wanting to continue updating the innovation and providing support, while others were successful in finding funding, for example, from sales of software associated with the innovation or donations from commercial entities. To sustain project activities, developers should consider fostering community and think ahead to a model of continued funding.

Major Findings

This section summarizes the major findings across the study as a whole, synthesizing two overall themes: interactivity and funding.

Interactivity

In a grounded theory study, there should be a central theme to which everything else is connected (Corbin & Strauss, 2014; Gibson & Hartman, 2014). In this study the theme is interactivity. It is the interactions with potential adopters that strengthen the innovation during
development, the dissemination methods, and support activities. This is the major takeaway from the study as a whole.

Interacting with potential adopters begins with development, perhaps bringing interested parties onboard as part of a multi-institution grant, or including plans for beta sites to gain valuable feedback in refining the innovation. The 14 cases from the study as a whole all worked with people from the beginning of the project, bringing together different areas of expertise and different contexts by being at different institutions. There may be variations—for example, developing more or less at one institution to begin with before involving other institutions—but none of these innovations were developed by a single researcher in a complete vacuum.

Interacting with potential adopters continues during dissemination initiatives, as developers in the 14 cases directly reached out to audiences through means such as targeting specific conferences, visiting departments in person, and running immersive workshops. The innovations often work creatively within existing academic structures to make them more interactive. Peer Instruction and Alice mentioned making sure there was time at the end of talks for discussion with audience members, and the PhET Simulations rented exhibit hall booths at conferences to interact directly with instructors in a less formal setting than a talk, allowing for conversation. Publishing papers are necessary—all of the innovations studied have published journal articles about the efficacy and research behind it—but all the cases go far beyond that to disseminate.

Finally, supporting adopters is a process of finding out the problems instructors encounter and then finding ways to assuage them. The developers all made themselves available to help with implementation, answering individual questions. Through this process, common issues became apparent, and this allowed for other mechanisms such as making professional development programming and writing instructor’s guides tailored to those common issues.

Funding

Innovations that have been successfully propagated require continuous funding. All project activities, from development, to dissemination, to supporting adopters, require funding—first through grant funds, and then finding a new revenue stream as ability and appropriateness to propose research grants diminishes. There is some structure within the National Science Foundation for scaling innovations, with the Type 1, Type 2, and Type 3 model. Many
innovations in this study move through the series of grants from initial idea to a national dissemination grant through that grant model. However, project activities did not end at “the innovation is disseminated, now it is done.” Sustaining adoption, updating project materials, and continuing to provide support for new adopters were important activities to many of the projects studied here, and there is no grant structure to do this. For some innovations studied, this meant struggles to continue updating materials and offering direct support, despite wanting to. For others, this meant finding a new source of revenue—donations from commercial interests, licensing fees, etc.—and when necessary establishing a new legal structure to manage incoming money, either through a commercial entity or through a non-profit.

This study as a whole looked at the progression of grant-funded projects from birth to moving out at eighteen: it begins with the close focus on NSF Program Directors (PDs) and Principal Investigators (PIs), talking with the PDs themselves and recently-funded PIs, then moves to study of three innovations with long histories of NSF funding (Peer Instruction, PhET Simulations, and Peer-Led Team Learning), and finally looked at additional projects that started with NSF funding and in most cases have either found new sources of funding or have ceased most project activities. Some PIs in the survey were aware they are not prepared for the task of nationally disseminating their materials, and wished the NSF had a marketing department to do it for them; projects in their fifteenth and twentieth years are also aware of the need to create their own means for continuing to propagate their product. It is a problem that everyone involved sees coming from a long way away, and currently it is up to PIs to determine the solution.

Major Findings Summary

The main finding from the study as a whole is the importance of interactivity in propagating an innovation—interacting with potential adopters at all stages of a project. Second to this is the importance of funding and thinking ahead to sustain project activities, which becomes particularly difficult after the innovation has been developed.
The three articles in the dissertation, while they provide new knowledge on their own, form a single overall study when looked at as a whole (Figure 5.1). They can be considered three simple stages in the study: identifying cases, model development, and refining the model. Cases identified in the first article are used in articles two and three. In article two, three of the cases were used for more in-depth study to build the model, taking it from an initial form to a more detailed, full form. In article three, eleven of the cases were used for briefer study to validate the full model, contributing further detail in one category in particular, support.

In addition to supplying and validating the cases for study, the process of identifying which innovations in STEM education are well-propagated in the first article yielded an axis of investigation carried across both of the other papers: innovation type by pedagogy and content. The project team as a whole considered carefully how to categorize the list of disparate innovations, which at first glance had almost nothing in common and had many different aims. The categorization scheme by pedagogy and content has proven contentious at conferences (many believe pedagogy and content are inextricably linked, and changing one will mean a change in the other), but the vocabulary this analysis provided allows for careful disentangling of
factors across innovations. This proved especially valuable in the third article, where support activities varied little by discipline or amount of resources needed or any other factors believed important to adoption decisions and implementation, but there were differences by innovation type. In addition, the findings from the first article regarding the amount of funding innovations have received and over how many years provided insight into the data collection and analysis for the second paper, looking carefully at the role of funding in propagation activities.

The second article led to the third, as the emerging model of successful propagation was mostly complete (Figure 5.2) but with a hole.

![Figure 5.2 Model from article two](image)

The first two steps in the process depicted in the model, develop interactively and disseminate interactively, were fleshed out substantially as of the end of the case studies documented in article two. The cases illustrated that the developers worked collaboratively with instructors, students, and researchers at their own institution and other institutions to develop the initial innovation, and set down specific critical components of their innovations with the
feedback of others. They found ways to interact directly with potential adopters, disseminating through highly interactive workshops and through visiting hundreds of departments in the country. But the third step, supporting adopters, presented the developers across all three cases with problems—they spoke confidently about the strong research behind the innovations and the impact of their dissemination efforts but were less sure their support methods were helpful to adopters. Even the PhET Simulations, which does not seem like an innovation requiring much support, struggled to host a community website that instructors could contribute to, knowing that instructors wanted more specific lesson plans to go with specific simulations and a community was a way to grow a bank of lesson plans. These cases indicated that the developers were constantly, actively looking for ways to support instructors in using their innovations but did not feel confident they were doing a good job of it.

This question of how to provide support led to the third article. It specifically investigated the remaining hole from the second article, (and also provided opportunity to check claims of other aspects of the model.) Now, with a repertoire of support activities from additional cases, the model is much more complete.

Discussion

The following is a discussion of new insights into interactive development, dissemination, and support activities when considering the project as a whole.

Collaborations at home and across schools. An early finding in this overall study was the idea of collaborations to build in additional stakeholders in the innovation from the start, which program directors noted was helpful to propagation. This led to the concept of interactive development, which initially captured collaborations across institutions. However, several of the innovations in this study did not have a multitude of active collaborations outside their campus, but were very interactive at home. For example, Learning Assistants, PhET Simulations, and Peer Instruction were all primarily developed at one institution, but were still highly interactive either across departments (Learning Assistants) or through departmental colleagues, hiring additional local developing staff, and student interviews (Peer Instruction and PhET)—not just taking learning data from students, but their opinions about the innovation, helping to shape it. Most of the innovations more closely matched the wishes of program directors, having collaborations across multiple institutions: Peer-Led Team Learning, Alice, CATME Team
Tools, Learning Assistants (in later stages of the project), Workshop Physics, POGIL, GeoGebra, and WebWork. While some of the innovations in the study break the norm of multiple-institution collaborations, it is likely that the interactions across institutions, especially being able to test materials in different contexts, led to more transferable products that more instructors can use. One quote illustrates this well:

“So it's been the three of us that have kind of worked in different environments... Because Tufts is a smaller private university. University of Oregon where David worked before he retired is a large public university. I was working in a liberal arts college environment. So we were able to hone materials for those different environments.” (Workshop Physics)

This idea of altering materials based on specific environments comes up much sooner in a project that already has multiple environments than one that gets data from other environments later.

Critical components or flexible materials? A pattern from the three in-depth cases was how feedback from various contexts led to the creation of critical components, or features that define the innovation and represent what an implementation should look like. This specific pattern of establishing critical components is less true of the additional cases from the support study, where in fact many of them emphasize the flexible, emergent nature of their innovation:

“I mean there are other companies that do stuff similar to us, but they create really really polished lesson plans or units that then they make that a priority and a focus to share. But at Geogebra, we kind of believe in not doing that, like we actually believe in allowing there to be a messiness to the process of learning and the construction of objects that are specific to a moment that a teacher needs in a classroom and a specific time or a specific location.” (GeoGebra).

CATME Team Tools has many options for modifying how an instructor can apply their teamwork model, even taking out components of it if they do not believe that component is important to teamwork:

“... when you use the CATME instrument online, you don't just click a single button and you get the whole instrument. You click a button for each of the different dimensions. And Richard Felder would never use that fifth dimension, which is having task-related knowledge, skills and abilities or developing, the willingness to develop those skills for the sake of the team. That was the compromise there, right? Was that the instrument has that factor but that the system electronically is designed so
you don't have to use it. Which, of course, means we haven't necessarily validated the instrument in all those permutations. Essentially, Richard uses the system at his own risk, not knowing whether or not it's actually as valid as the instrument when you use the whole thing.” (CATME Team Tools)

This raises the related issue of fidelity of implementation, which is seen as critical to program success in the implementation literature (Fixsen et al., 2005). But this theme of letting users use the materials in whatever way fit their context is in many of the additional cases in the support study.

Working across disciplines. The CATME Team Tools story above leads into another dimension of interactive development not explored in the three larger case studies: working across disciplines. Developers in the support study frequently brought up work they had done or conversations they had had with researchers in other STEM fields. The CATME Team Tools developing team has had multiple disciplines from the start, which raised unique issues of both conceptual ideas (such as with leaving out a dimension of the instrument) and communication within the project team:

“We had different ways of talking about things. […] early on, Misty Loughry from management said, "Every model of teamwork has monitoring in it." And she was just absolute that that had to be in there. […] And the result of that was, we did put items into our original research. We had items that were related to monitoring and items that were related to feedback, but in a statistical sense those collapsed into a single factor. And she realized, "Oh, okay," right? "This really is focused on what you can observe as a behavior." And it all came together in that sense.” (CATME Team Tools)

The CATME project is probably the most interdisciplinary from the innovations I studied (engineering, management and psychology), but interactions with other disciplines did not have to be full-blown collaborations to lead to developments in some cases. Even conversations and talks from conferences could have an impact: “Chris Rasmussen came to a Chemistry Gordon Conference and gave a talk about what he was doing in math. Renee Cole and Marcy Towns just thought it was really interesting and they immediately thought, ‘Physical chemistry is a lot like math, I wonder if we could do this kind of analysis in POGIL physical chemistry classrooms?’” (POGIL). This led to an entire research area within POGIL.
Interactivity across disciplines came into play with dissemination as well. Several cases mentioned that they experienced growth in users when their innovation had been at another disciplinary conference. CATME Team Tools had several disciplines involved on the project team, so they had a presence at each of those conferences to begin with.

*Leveraging professional societies.* Another activity the program directors noted as useful to propagation was collaborations with professional societies. During the focus groups, many of the disciplines pointed to the American Physical Society’s New Faculty Workshop as a successful mechanism for reaching a wide swath of instructors with research-based pedagogy. They wanted to see more relationships between PIs and professional societies. Several of the innovations in the support study had a collaboration with a professional society. Learning Assistants experienced massive growth when PhysTec, an initiative run by the American Physical Society and the American Association of Physics Teachers, secured a grant to fund implementations of Learning Assistants at schools across the country (similar to the mini-grant program run by PLTL). Another innovation, WebWork, wrote a joint dissemination grant with the Mathematics Association of America (MAA). This partnership bolstered the visibility of WebWork, growing dramatically from 100 institutions to 1000 in the first year of the grant: “But once the MAA was involved and started hosting a demonstration server, then a lot of other people ... the visibility was raised enormously and a lot of people started joining in; and are still joining in I might add, at this point.” (WebWork). The visibility and the resource of hosting for interested institutions allowed more people to try WebWork before having to install it locally, a process that takes some time and local resources. The WebWork team indicated that they had hoped for a permanent housing of WebWork within the MAA infrastructure, but without additional funding, MAA does not have the resources to continue their involvement. A pattern across innovation interactions with professional societies is that the professional societies are structured for events and short term grant-funded projects. PhysTec can help spread an innovation with a grant, MAA can host an innovation with a grant, and the New Faculty Workshop (also grant-funded) is an event that happens once a year. It is likely that professional societies should be leveraged with this specifically in mind: they can provide a visibility and dissemination boost, but it is short-term.
Limitations

This study had the enormous benefit of feedback from the entire project team with every publication, and some input on ideas during regular weekly meetings. Other checks were in place at many points, such as collecting additional sources of data beyond interviews, which on occasion proved a crucial step to prevent an erroneous claim. Checking my own interpretation of what each innovation was at the start of this project with input from the original PIs themselves also prevented potential issues when drawing conclusions later between project type and propagation strategies used.

One limitation in being able to make claims is the issue of what was identified in the first place by experts to be well-propagated. While everything on the list was exhaustively checked to ensure that it was in fact well-propagated, there is the issue of items that did not make it onto the list. For example, one claim from this study is that content innovations seem more difficult to propagate, and the lack of new content in courses is documented in physics and chemistry (DeBoer, 1991), but less certain in other disciplines. It may be that experts simply did not consider content changes in their responses in other disciplines. However, this may be less a limitation and more an opportunity for future research, to delve further into content innovations by discipline and the reasons they do and do not propagate.

A further limitation of this study is the close focus on the NSF alone. While findings so far have proved relevant in my sphere of education research, applying conclusions from this work to innovations developed in other circumstances and funded by other agencies may be questionable.

Future Research

The Role of Discipline in Propagating Innovations

There are several indications in the literature that the discipline an innovation comes from and in which an individual instructor resides is important to the propagation of the innovation: the complexities of the instructional system indicate that disciplinary forces inform individual teaching decisions and the overall perception of the value of changing teaching (Austin, 2011; Gess-Newsome et al., 2003; Lattuca, 2011; Lund & Stains, 2015). For example, Lund & Stains (2015) found that chemistry instructors adopted fewer evidence-based teaching practices than did
physics instructors, and note that the departmental attitudes toward student-centered teaching
likely played a role in the differences. One finding from this study was the viewpoint of NSF
PDs regarding the role that disciplinary societies can take in propagating innovations, noting the
success of the New Faculty Workshop in physics (e.g., Henderson, 2008). Disciplinary
differences appeared in this study in several ways:

1. The discipline seemed to correlate with behaviors about branding an innovation vs.
keeping it a concept that individual instructors can reinvent on their own. Looking at the
innovations reported as well-propagated by experts in physics and engineering, almost all of the
innovations in physics are “branded,” that is, have a specific name for the pedagogy and a
specific model for how it should be done, while in engineering terms for new pedagogy are more
open, and it is harder to identify an individual PI who initially developed it (without stepping on
any professional toes.)

It is still unclear even after hours of discussion with the project team and others why this
might be, and work should be done to understand the nature of branding by discipline and
whether the current state is desirable in either discipline (for example, perhaps branding is
actually detrimental in some way, or leaving an innovation too open is detrimental.)

2. As mentioned in the discussion, the nature of the discipline impacts the existing
structures in place that can serve to propagate innovations. In physics, the professional societies
are willing to work with PIs and include innovations in events such as the New Faculty
Workshop; in chemistry, professional societies deign to include a section of education research at
their meetings, but are not actively involved in propagating chemistry education materials.
However, there are networks of instructors that fill that purpose. More work needs to be done
with the other disciplines to determine what structures are there to leverage and how best to do it.
In addition, the specific role that professional societies can fill in propagating innovations should
be investigated further, as this work indicates they excel in providing short events and initiatives
but may not be able to champion innovations for long periods of time.

Supports by Implementation Stage

While the questions in the final stage of the study focused primarily on initial
implementation, developers discussed several of the other stages of implementation as well. The
review of implementation literature by Fixsen and colleagues (2005) identifies six stages of implementation:

- Exploration and adoption – gaining information about a program or innovation and making the decision to adopt
- Program installation – mobilizing resources (e.g. financial, staff, and policies) to begin the program
- Initial implementation – putting the new change into place
- Full operation – the program is running, it is on its way toward becoming standard practice in the organization
- Innovation – following the successful full operation, sites can tailor the program to fit their unique needs with feedback from the original source
- Sustainability – the program is continued at the site despite the usual changes an organization goes through (e.g., staff, funding, external influences)

Table 5.1 below shows examples of instances in the interviews where different stages were being discussed, and support activities most associated with these stages in the data.

Table 5.1 Quotes regarding supporting adopters at implementation stages

<table>
<thead>
<tr>
<th>Implementation Stage</th>
<th>Support Activities Used</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Exploration &amp; Adoption</em></td>
<td>Responding to individual questions, providing community, technical installation support</td>
<td>First, letting people even know it exists. Then supporting them as they dabble in it, supporting them as they actually implement it the first time, and then supporting them as they get deeper into their implementation of anything like WebWork. (WebWork)</td>
</tr>
<tr>
<td><em>Program Installation</em></td>
<td>Policy assistance, technical installation support, connecting users</td>
<td>It's hard for somebody to say hi, I've got this little program, provost, will you give me 100,000 bucks. (Learning Assistants)</td>
</tr>
<tr>
<td><em>Initial Implementation</em></td>
<td>Responding to individual questions, technical</td>
<td>When we were trying to get this going and still today, we have</td>
</tr>
</tbody>
</table>
Overall, responding to individual questions is seen across all the stages, and is a prominent support mechanism in most of them. Two stages, program installation and innovation, drew more heavily upon the support activities of policy assistance and custom technical support, respectively. Those activities exemplify those specific implementation stages, as program
installation can involve mobilizing stakeholders and policy to prepare for initial implementation, and innovation can involve making modifications after successful implementation with fidelity to the original source. Future work should consider the other stages in more detail to learn which supports are most useful at each stage and why.

Recommendations

In STEM education, we talk a lot about scientific literacy, meaning a basic level of being able to think about science from a good citizen standpoint (Trefil, 2008). We now also need financial literacy in the sciences. “Financial literacy” varies from finance author to author but typically means learning to avoid common money-making-and-saving pitfalls. Here, I suggest we discuss something similar in the sciences, “sustainability literacy.” The grant model is not going away; it is how research is funded in STEM education, and it is going to continue to be a vector for changing STEM teaching at large. One key takeaway from this study was the issue of sustainability; grants can be given for initial development and dissemination initiatives, but not for keeping the project going. That third stage is critical to see the benefits of the research that was funded in the first place—at this stage there is a product that works for many instructors, it is known in the research community, people want to use it—but support during initial implementation is key and is something PIs cannot provide without additional funding. PIs need a resource to look at their project through a more commercial lens (as this is not a skill that comes naturally to most academics) and determine: what is a unit of sale here? (Is it a book, is it software?) What is that unit of sale worth? Or, who would consider donating? How can those relationships with commercial interests begin? What financial structure is most appropriate for the goals of this project, a non-profit or a commercial entity? PIs need resources to learn to determine a business model (commercial or not) to sustain project activities.

Finally, a major finding from this study is the importance of interactivity. Funding agencies such as the NSF should consider underlining the importance of interacting with potential adopters. They have already shifted language from “dissemination” to “propagation” in their request for proposals (“Improving Undergraduate STEM Education: Education and Human Resources (IUSE: EHR),” 2015). However, propagation is not currently considered by review panels and program officers as a critical element to proposals—a good idea and the promise of publishing about it should not be sufficient for the proposal to be funded. The activities of
successful developers are so far removed from typical practice it requires a dramatic change in mindset about grant-funded research projects. PIs need access to resources and training in a propagation mindset and in planning specifically for propagation if the current situation in STEM education is going to change.
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APPENDIX A

Human Subjects Institutional Review Board Letters
HSIRB for Peer-Led Team Learning Case Study

Date: January 30, 2013

To: Charles Henderson, Principal Investigator
    Patricia Reeves, Co-Principal Investigator
    Raina Khatri, Student Investigator

From: Amy Naugle, Ph.D., Chair

Re: Approval not needed for HSIRB Project Number 13-01-37

This letter will serve as confirmation that your project “Successful Propagation of Research-based Instructional Strategies: A Case Study of Peer-Led Team Learning” has been reviewed by the Human Subjects Institutional Review Board (HSIRB). Based on that review, the HSIRB has determined that approval is not required for you to conduct this project because you are analyzing an instructional strategy and not collecting personal identifiable (private) information about individuals.

Thank you for your concerns about protecting the rights and welfare of human subjects.

A copy of your protocol and a copy of this letter will be maintained in the HSIRB files.
HSIRB for Peer Instruction Case Study

Date: January 22, 2014

To: Charles Henderson, Principal Investigator
    Raina Khatri, Student Investigator for thesis

From: Amy Naugle, Ph.D., Chair

Re: HSIRB Project Number 14-01-24

This letter will serve as confirmation that your research project titled “The Propagation of Peer Instruction: A Case Study” has been approved under the expedited category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note: This research may only be conducted exactly in the form it was approved. You must seek specific board approval for any changes in this project (e.g., you must request a post approval change to enroll subjects beyond the number stated in your application under “Number of subjects you want to complete the study”). Failure to obtain approval for changes will result in a protocol deviation. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

Reapproval of the project is required if it extends beyond the termination date stated below.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: January 22, 2015
Date: September 18, 2017

To: Charles Henderson, Principal Investigator
   Raina Khatri, Student Investigator for dissertation

From: Amy Naugle, Ph.D., Chair

Re: Approval not needed for HSIRB Project Number 17-09-19

This letter will serve as confirmation that your project titled “Propagation of STEM Education Innovations Study” has been reviewed by the Western Michigan University Institutional Review Board (WMU IRB). Based on that review, the WMU IRB has determined that approval is not required for you to conduct this project because you are not collecting personal identifiable (private) information about individual and your scope of work does not meet the Federal definition of human subject.

45 CFR 46.102 (f) Human Subject

(f) Human subject means a living individual about whom an investigator (whether professional or student) conducting research obtains
(1) Data through intervention or interaction with the individual, or
(2) Identifiable private information.

Intervention includes both physical procedures by which data are gathered (for example, venipuncture) and manipulations of the subject or the subject’s environment that are performed for research purposes. Interaction includes communication or interpersonal contact between investigator and subject. Private information includes information about behavior that occurs in a context in which an individual can reasonably expect that no observation or recording is taking place, and information which has been provided for specific purposes by an individual and which the individual can reasonably expect will not be made public (for example, a medical record). Private information must be individually identifiable (i.e., the identity of the subject is or may readily be ascertained by the investigator or associated with the information) in order for obtaining the information to constitute research involving human subjects.

“About whom” – a human subject research project requires the data received from the living individual to be about the person.

Thank you for your concerns about protecting the rights and welfare of human subjects.

A copy of your protocol and a copy of this letter will be maintained in the HSIRB files.
The text in the screenshot reads: “Physical Review Physics Education Research (PRPER) is an online-only, open access journal that is distributed without charge, and financed by article-processing charges (APCs) to the authors or to the authors' institutions. To defray editorial, composition, hosting, and archiving expenses, there is an APC of $1900 for a regular article; $1200 for a Short Paper. [...] Articles in PRPER are published under the terms of the Creative Commons Attribution license (3.0 Unported or 4.0 International). Copyright is not transferred to APS for articles published in PRPER.”

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