How Static is the Statics Classroom?
An investigation into how innovations, specifically Research-Based Instructional Strategies, are adopted into the Statics Classroom

Stephanie Leigh Cutler

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Maura Borrego (Chair)
Stephanie G. Adams
Brian Kleiner
Lisa McNair

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ABSTRACT

The purpose of this dissertation is to investigate how educational research, specifically Research-Based Instructional Strategies (RBIS), is adopted by education practice, specifically within the engineering Statics classroom. Using a systematic approach, changes in classroom teaching practices were investigated from the instructors' perspective. Both researchers and practitioners are included in the process, combining efforts to improve student learning, which is a critical goal for engineering education. The study is divided into 3 stages and each is discussed in an individual manuscript. Manuscript 1 provides an assessment of current teaching practices; Manuscript 2 explores RBIS use by Statics instructors and perceived barriers of adoption; and Manuscript 3 evaluates adoption using Fidelity of Implementation.

A common set of concurrent mixed methods was used for each stage of this study. A quantitative national survey of Statics instructors (n =166) and 18 qualitative interviews were conducted to examine activities used in the Statics classroom and familiarity with nine RBIS.

The results of this study show that lecturing is the most common activity throughout Statics classrooms, but is not the only activity. Other common activities included working examples and students working on problems individually and in groups. As discussed by the interview participants, each of Rogers' characteristics influenced adoption for different reasons. For example, Complexity (level of difficulty with implementation of an RBIS) was most commonly identified as a barrier. His study also evaluated the Fidelity of Implementation for each RBIS and found it to be higher for RBIS that were less complex (in terms of the number of critical components). Many of the critical components (i.e. activities required for implementation, as described in the literature) were found to statistically distinguish RBIS users and non-users.

This dissertation offers four contributions: (1) an understanding of current practices in Statics; (2) the instructor perspective of the barriers to using RBIS in the classroom; (3) the use of Fidelity of Implementation as a unique evaluation of RBIS adoption, which can be used by future engineering education researchers; and (4) a systematic approach of exploring change in the classroom, which offers new perspectives and approaches to accelerate the adoption process.

Dedication

I dedicate this dissertation to my Papa, Richard Sheaffer. Through his example I learned what it meant to be an amazing person and an excellent engineer. He never missed an opportunity to tell me how proud he was of me and how much he loved me. Though he passed away last November and wasn't able to see this dissertation in its final form, I know he is always with me and he would be so proud of the work enclosed in this dissertation.

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Chapter 1:

Introduction

The overall goal of engineering education is to improve student learning in engineering. Using a range of different methods, a variety of topics can be explored that influence learning. A variety of faculty members become involved in this process: those who are in the classroom and those who conduct research on the different elements of learning. It has been repeatedly noted by the field of engineering education that these two groups have become separate with limited communication across the gap (Jamieson & Lohman, 2009; National Research Council, 2012). By understanding the gap between research and practice, we, the engineering education community as a whole, can make strides to bring innovative practices developed through research to the classroom where it can directly aid in improving student learning. Examining one side of the research-to-practice gap will not improve student learning; instead, my dissertation brings the practitioner perspective to the researchers while examining the implementation of research in the classroom.

My dissertation focuses on the context of engineering Statics. As a sophomore-level course, Statics content is foundational to the engineering curriculum acting as a prerequisite course for dynamics, mechanics of materials, and all other mechanics-based courses (P. Steif, 2004). Throughout the literature, it is assumed that the traditional way Statics is taught is through lecture (Coller, 2008; Rutz et al., 2003; P. S. Steif & Dollar, 2005, 2009). To investigate this assumption, an investigation of the current practices in Statics (Manuscript 1) was completed. To understand what changes need to be made to the Statics classroom and to evaluate progress, it is important to understand what the current practices are.

It has been frequently discussed within the engineering education community that there is a gap between what was being developed through research and what was being used in the classroom (Jamieson & Lohman, 2009; National Research Council, 2012). Numerous studies have investigated ways of improving student learning and engagement (Bruffee, 1995; Crouch & Mazur, 2001; Dochy, M., Van den Bossche, & Gijbels, 2003; R. M. Felder & Brent, 2009; Michael Prince & Felder, 2007), but it is still assumed that most practices have stayed the same. To better understand instructors' views on this research, this dissertation investigated the familiarity of Statics instructors with a set of Research-Based Instructional Strategies (RBIS) that were developed through educational research communities. This investigation focuses on the instructors' perspective on the research that is meant to help them. This study aims to directly connect the practitioners with the research.

Throughout the engineering education community, different members hold different perspectives on RBIS and what it means to implement them. Therefore, the third element of this study seeks to discover among instructors who claim to be using an RBIS, whether they are using the RBIS as indicated by the literature. Within K-12 education, it is common to measure the level with which an innovation follows the original intent, called the Fidelity of Implementation. The applicability of Fidelity of Implementation was investigated as a possible way to evaluate how RBIS are being implemented in the higher education classroom, particularly Statics.

The overall goal of this dissertation is to investigate the adoption of new practices, specifically Research-Based Instructional Strategies (RBIS), in the Statics classroom. Each of the individual studies in this dissertation is a step in exploring this phenomenon. First, before changes to new practices can be examined, current practices must be established. For most research, this is done through literature reviews of published results from research studies. However, this dissertation is exploring the Statics classroom, where the current practices are not regularly documented. Therefore, the first step in this dissertation was to characterize the changes happening in the Statics classroom to explore what common teaching practices were being used in the current Statics classroom (Manuscript 1). The next step was a more direct characterization of the adoption of RBIS. First, instructor familiarity with RBIS was examined, which helped to understand if RBIS had already been implemented in the classroom. However, knowing that RBIS are or are not being used is helpful, but does not offer any directions for future work and does not aid in understanding instructor motivations about adoption. Therefore, instructors were also asked to discuss the characteristics of each RBIS that presented barriers to adoption (Manuscript 2). The final step in this dissertation was to evaluate the adoption process. When adopting an RBIS, adapting some of the elements to fit within the context of the specific university/classroom can be helpful. However, these changes are not generally discussed or studied as to the impact of these adaptations. Part of this is discovering how many changes an instructor can make to RBIS before they are actually implementing something else or losing the value of the original RBIS. Therefore, this dissertation sought to explore the application of a Fidelity of Implementation framework to RBIS and their implementation in the Statics classroom. Fidelity of implementation was developed in the context of K-12 education to evaluate how well innovations follow the original intent (Manuscript 3). This is an important element for documenting the adoption of new practices. In summary, to fully investigate how RBIS are being adopted into the Statics classroom, this dissertation characterized current practices, Statics instructor familiarity with RBIS, the barriers instructors see to adopting, and, finally, investigated adopting practices for possible adaptation.

The presentation of these studies will be through three individual manuscripts that will be discussed in the following section and presented in Chapters 2-4 of this dissertation. After discussing the manuscript style of this dissertation, there will be an overview of the theories used to frame each manuscript, and a brief review of Research-Based Instructional Strategies that will play a central role in two of the three manuscripts. Finally, the common set of the methods that will be used in each manuscript will be discussed.

Overview of Manuscripts

As a manuscript dissertation, this dissertation will present three ready-to-submit articles that are combined to form one dissertation. Where a traditional dissertation contains typically five chapters including an Introduction, Literature Review, Methods, Results, and Discussion & Conclusion (Robinson & Dracup, 2008); this dissertation will include the five chapters including an Introduction, Manuscript 1, Manuscript 2, Manuscript 3, and Conclusion. Each Manuscript will have a separate Introduction, Literature Review, Methods, Results, and Discussion & Conclusion, as each will be a single ready-to-publish article. Though the chapters cover the same information, the manuscript dissertation presents them in a different way, which can be beneficial for a number of different reasons. First, the individual manuscripts are ready to be submitted as journal articles once the student graduates; this can help them in their future career (Robinson & Dracup, 2008). Second, some studies have common threads, but lend themselves to be highlighted in individual discussions. The selection of a manuscript dissertation was dominated by this second reason. I used a common set of methods to look at a central topic from three different perspectives.

Another influence on choosing a manuscript dissertation was that I was working on a National Science Foundation grant investigating RBIS adoption in engineering sciences courses. The work on the NSF grant aided in the development of this study and will be discussed later. Due to the experience gained working on the NSF grant, I was able to identify gaps in the current research that my dissertation would be able to fill. As gaps were identified within this research, I realized that the results of my study could greatly benefit both researchers and practitioners of engineering education, leading to my desire to publish these studies quickly for dissemination within the engineering education community.

Manuscript 1 begins the investigation by establishing the common practices within the Statics classroom. When discussed in the literature, it is assumed that Statics is a lecture-based course with limited participation from the students. This study found that nearly all of the instructors who participated required some element of participation from their students. This manuscript provides a better understanding of common practices within the Statics classroom.

Manuscript 2 furthers the investigation by specifically targeting the dissemination of Research-Based Instructional Strategies (RBIS) into the Statics classroom. RBIS have been developed through Science, Technology, Engineering, and Math (STEM) education research to aid in student engagement and learning; however, there has been limited investigation into how often these RBIS are being used outside of the developing institution (exceptions include Cutler, Borrego, Henderson, Prince, & Froyd, 2012; J. Froyd, Borrego, Prince, Henderson, & Cutler, 2012; Henderson & Dancy, 2007; Michael Prince, Borrego, Henderson, Cutler, & Froyd, 2012). This manuscript aims to document instructor familiarity with these RBIS and the influences on faculty members' decisions about using these RBIS, specifically targeting the challenges or barriers faculty members perceive to adopting these RBIS in their classroom.

Manuscript 3 concludes the investigation by comparing the activities established in Manuscript 1 to the RBIS discussed in Manuscript 2 to investigate instructors who claim to be using an RBIS, whether they are using them as intended by the literature. In other words, high fidelity is when a faculty member says they are using an RBIS and also spending time on the appropriate activities to complete that RBIS. This measure is called Fidelity of Implementation. Fidelity of Implementation is defined as the measure of how well an implemented intervention (in this study, RBIS) follows the original intent (O'Donnell, 2008).

This dissertation forms a systematic view of the Statics classroom and the innovations that have been integrated into this fundamental course. These manuscripts begin by establishing a starting point for the investigation through the exploration of the current practices in Statics, then they look specifically at how educational innovations have been integrated and the barriers that prevent the innovations' full diffusion. Finally, by investigating not only if the innovations are being used, but also if they are being used as intended, a dialogue can begin about what next steps need be taken to ensure RBIS implementation and consistent language during the discussion. The research questions for the overall dissertation are mapped to the manuscript where they will be addressed in Table 1.

Table 1 : Mapping Research Questions to Manuscripts

Chapter	Manuscripts	Research Questions	Methods
2	MS 1: What's Happening in the Statics Classroom: A study of current practices	RQ 1a: What common practices (activities) are being used in the Statics classroom? RQ 1b:What unique characteristics of Statics influence these practices?	**QUALQUANT –** Even emphasis on qualitative and qualitative data
3	MS 2: Dynamic Change in the Statics Classroom: An investigation faculty perceptions of barriers to adoption of innovative teaching practices	RQ 2: What barriers do faculty members perceive to the adoption of RBIS?	**QUAL**quant – Heavier emphasis on qualitative data; less emphasis on quantitative data
4	MS 3: Fidelity of Implementation in the Statics Classroom	RQ 3a: With what degree of fidelity are RBIS being implemented within the Statics classroom? RQ3b: Do the critical components that characterize an RBIS discriminate between Statics faculty members who claimed to use RBIS and those who do not?	qual**QUANT –** Heavier emphasis on quantitative data; less emphasis on qualitative data

This introduction chapter is meant to provide the readers with an overview of the different components of the overall dissertation; this includes a number of elements common among all manuscripts. This means that many of the elements discussed in this chapter will also be discussed in each individual manuscript. Where these sections may seem redundant, each manuscript is meant to stand alone, requiring the information to be present within each individual manuscript.

Overview of Theory

Diffusion of Innovation (DOI) is the framework for this dissertation. However, it is only directly used in one manuscript. Ultimately, the purpose of this dissertation is to investigate how Statics practices are changing and adopting Research-Based Instructional Strategies (RBIS). However, before practices can be changed, current practices must be evaluated (Manuscript 1). Manuscript 2 directly uses the characteristics described in DOI to explore the barriers instructors face when adopting RBIS in their classrooms. Finally, DOI discusses how originally innovations were considered to be “an exact copying or imitation of how the innovation had been used previously in a different setting”; however, more recent DOI literature has acknowledged that giving instructors the freedom to adapt the innovation to their specific context can help with adoption (Rogers, 2003). However, DOI does not offer a way to evaluate these changes. After consulting K-12 educational research, Fidelity of Implementation (FOI) was discovered as a way of evaluating how well the implemented innovation follows the original intent and became the framework used in Manuscript 3. A more thorough exploration of the theories used in each manuscript is discussed in the following sections.

Theory in Manuscript 1

Manuscript 1 is a study of current practices. Where it is very important to use a theoretical framework for research studies, Manuscript 1 is meant as survey of the current practices within Statics, addressing the research questions: “What common practices (activities) are being used in the Statics classroom?” and “What unique characteristics of Statics influence these practices?,” and does not follow an explicit theoretical framework. However, this is an important step for both the research and practice communities. Consider the engineering design process. One of the first steps the designer takes is benchmarking current practices. Engineering education seeks to improve student learning in engineering classes, but has not benchmarked the practices that are already being used. Manuscript 1 provides this benchmarking. Borrego, Douglas, and Amelink also say that surveys of what is happening is a common starting point (2009).

Theory in Manuscript 2

Manuscript 2 uses the Diffusion of Innovation (DOI) framework to explore instructor use of RBIS and the barriers they see to adoption. In the 1960's, DOI was formalized as a framework for understanding how technological innovations disperse throughout a social system (Rogers, 2003). Since then, DOI has been used in a variety of settings, including education, to explain how new technology and practices are being adopted. Within STEM education, the dissemination conversation has begun to be framed using the DOI framework (Cutler et al., 2012; Henderson & Dancy, 2007; Henderson, Dancy, & Niewiadomska-Bugaj, submitted 2012; Macdonald, Manduca, Mogk, & Tewksbury, 2005). The DOI framework also lends itself to answering the research question addressed in Manuscript 2: "What barriers do faculty members perceive to the adoption of RBIS?" DOI provides five characteristics of innovations that act as influences on adoption: Relative Advantage, Compatibility, Complexity, Trialability, and Observability. These influences can be seen as positive (advantages) or negative (barriers).These characteristics were then used as a lens for answering this research question.

Theory in Manuscript 3

Fidelity of Implementation (FOI) is the final framework that is used in this study. FOI is a new concept within engineering education adding an additional element to the investigation to explore the applicability of Fidelity of Implementation within engineering education as a potential framework. Therefore, Manuscript 3 addresses the research questions, "With what degree of fidelity are RBIS being implemented within the Statics classroom?" and "Do the critical components that characterize an RBIS discriminate between Statics faculty members who claimed to use RBIS and those who do not?" Fidelity of Implementation, especially as it is discussed by Hall and Loucks (1978) and Mowbray and his colleagues (2003), primarily highlights the need for establishing and evaluating the critical components of an innovation. Critical components are the elements of an innovation that are necessary for the innovation to be implemented without "drastic mutation" (Hall & Loucks, 1978). The idea of critical components is directly aligned with the engineering design process; they are the engineering specifications for the innovation. Though more research should explore this framework, it does offer a way to evaluate how well the innovations of RBIS are following the theory and offers a way to track any adaptations that are made to an RBIS during implementation.

Each of the above frameworks will be used to investigate the adoption of RBIS within the Statics classroom. The next section will discuss the specific RBIS under investigation in all three manuscripts

Overview of DOI Literature

The focus of this literature review is twofold. First, the dissemination literature will be discussed as it relates to the Diffusion of Innovation (DOI) framework (Rogers, 2003) used in this study exploring the major elements of DOI including: the *innovation, time,* and *communication channels*. There will also be a brief discussion of research studies that have used DOI in an educational setting.

Dissemination Literature

Though many theories for dissemination and diffusion are discussed throughout the literature, one of the most influential is Diffusion of Innovation (DOI) (Rogers, 2003; Stirman, Crits-Christoph, & DeRubeis, 2004), which was used to guide this study. The reasons Diffusion of Innovation (DOI) was chosen for this study are listed in Table 2. The first reason is that Diffusion of Innovation is one of the most widely used and well established frameworks for dissemination research. It has been used in multiple studies within educational settings (including STEM education and engineering education), as well as in theses and dissertations (Johnson, 2001; Watson, 2007). Within these studies, there have been very few contradictory findings, providing additional validity and support for the framework. Many of the other frameworks share multiple components with DOI and some were even based on the DOI framework. However, the other frameworks do not offer a complete picture of the overall diffusion process. Many focus on one element: the process, communication, or the attributes of the innovation, but DOI offers a framework for each of these elements as well as how they fit together. The general overview nature of DOI was one of the reasons it was chosen, since limited work has been done within the engineering education field, there is not a specific theory that would be more applicable for this particular study. Though in recent years, DOI has been used as the primary theory for studies investigating RBIS use in the classroom (Cutler et al., 2012; Henderson et al., submitted 2012).

Table 2: Reasons for choosing Diffusion of Innovation Framework

Reasons for Choosing DOI
- Widely used and well established - Shares components with other frameworks - Basis for many other frameworks - Offers a complete picture, not just one aspect

Diffusion of Innovation has four major elements: *innovation*, *communication channels*, *time,* and *social system*. Each element is important to examining the overall phenomenon of innovation adoption; however, this study focuses on the barriers Statics instructors face when deciding to adopt specific educational innovations. Since the focus of this study is on the individual Static instructors, the *social system* element of DOI will not be specifically discussed. The remaining DOI elements will be discussed as well as their presence in the broader dissemination literature.

Characteristics of the Innovation

Since the focus of this study is on barriers to adoption, the characteristics of the innovation play a very important role. According to Rogers, *innovation* can be characterized by traits that increase the rate of adoption, such as: (1) *Relative Advantage*, (2) *Compatibility*, (3) *Complexity*, (4) *Trialability*, and (5) *Observability* (2003). Due to their influence on the rate of adoption, these characteristics can be viewed as benefits that increase the rate of adoption, or barriers that hinder the rate of adoption. As part of the data collection for this study, interview participants were asked to use the DOI characteristics to evaluate Research-Based Instructional Strategies (RBIS). The definitions (both Rogers and those provided to participants) are provided in Table 3.

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Table 3: Diffusion of Innovation Characteristic Definitions

Characteristic	Definition provided to participants	Rogers Definition (Rogers, 2003)
Relative Advantage	The benefit of doing [an RBIS] over lecturing	"The degree to which an innovation is perceived as better than the idea it supersedes"
Compatibility	The similarity to how [an instructor] thinks learning occurs	"the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters"
Complexity	How hard it would be to use [the specific RBIS]	"the degree to which an innovation is perceived as difficult to understand and use"
Trialability	How easily [the instructor] could try [an RBIS] before using it	"the degree to which an innovation may be experimented with on a limited basis"
Observability	How easy it is to see how well [an RBIS] is working	"the degree to which the results of an innovation are visible to others"

These characteristics are unique to the DOI framework, but other dissemination literature has developed similar, but different characteristics for innovations; these will be discussed next.

In 1993, Hutchinson and Huberman composed a literature review of dissemination literature. Within this review, they proposed seven predictors of successful dissemination: accessibility, Compatibility, quality, redundancy, linkage among users, engagement, and sustained interaction. *Accessibility* relates to how available the innovation material is to potential adopters. *Compatibility* relates to how the innovation fits into the actual application or "real world." *Quality* refers to evidence that the innovation will work, or the evaluation and validation showing the innovation will be successful. *Redundancy* refers to ensuring that the potential adopters are exposed to the innovation through multiple communication and dissemination channels. *Linkage among users* refers to ensuring interpersonal communication among the users.

By providing opportunities for the users to engage with the new program will help to encourage *engagement* to increase the chances of success. The final predictor is *sustained interaction* described in extended detail compared to the other six predictors. Sustained interaction ensures the adopters will have continued access to the researchers or change agents throughout the implementation process. Hutchinson and Huberman's predictors are comparable to Rogers' characteristics mentioned earlier as shown in Table 4.

Table 4: Comparison of Hutchinson & Huberman's predictors to Rogers' characteristics

Hutchinson & Huberman's Predictors	Rogers Characteristics
Accessibility	Elements of Complexity
Compatibility	Compatibility
Quality	Relative Advantage and Observability
Redundancy	Discussed as part of Communication Channels
Linkage among users	Discussed as part of Communication Channels
Engagement	Trialability
Sustained Interaction	Discussed as part of Communication Channels

Time

Rogers' discussion of time leads to his innovation-decision process; the process is based around the stages a potential adopter goes through while adopting a new innovation (Rogers, 2003). The first stage is *knowledge*, where the potential adopter gathers knowledge of the innovation's existence. The second stage is *persuasion*, when an opinion is formed about the innovation. Next, the potential adopter makes a *decision* about whether or not to implement the innovation. The fourth step is actually *implementing* the innovation, and the final step is *confirmation* when the adopter decides whether or not to continue using the innovation. Henderson and Dancy used the innovation-decision process to investigate where physics faculty members left the process when adopting research-based instructional strategies (RBIS) for the classroom (2007). This study was repeated for engineering sciences instructors, including Statics (Cutler et al., 2012).

Both of these studies found that there were more faculty members who had progressed past the first stage and had an awareness of many of RBIS; however, many faculty members discontinued their use of an RBIS after trying it or did not try it (Cutler et al., 2012; Henderson et al., submitted 2012).

There are a number of other dissemination frameworks that explore the process of potential adopters when making a decision about adopting an innovation. These will be briefly discussed next.

Foertsch and colleagues investigated math and chemistry professors' likelihood of adoption based on four methods of dissemination using Hutchinson and Huberman's framework as a starting point for their research (1997). Through interviews, three stages of the adoption process emerged during this study: exposing (initially informing potential adopters to make them want to learn more), informing (basic information and evidence for reform), and teaching (the specifics of how to implement the reform) (Foertsch et al., 1997). These stages are similar to those included in the DOI innovation-decision process. Another finding from Foertsch et al is that the appropriate method for dissemination depends on the current stage of the potential user, which is reflected in DOI communication channels that will be discussed next. Foertsch et al. contributed to the dissemination literature by offering increased evidence in support of elements present in other dissemination and diffusion literature.

More recently, Frank and colleagues began with a theoretical framework that had been used to examine the diffusion of computers within school systems, but ultimately developed their own framework for how teachers gain knowledge of an innovation (2011). Their framework began with teachers being exposed to an innovation that made them want to *focus* on the implementation of that innovation. Then, teachers want to explore the innovation; a stage they named *fiddle*. The final stage, *friends*, was confirming with colleagues and gaining additional knowledge from them. Frank et al.'s focus, fiddle, friends model was confirmed by their survey of elementary school teachers (2011). Again, these elements are similar to the DOI elements and the elements discussed in other diffusion theories.

Social Marketing Theory has also been used to discuss dissemination (Stirman et al., 2004). According to this theory, there are four stages of dissemination: market analysis, market segmentation, market strategy, and evaluation. Market analysis calls for the direct consultation with practitioners who will be using the innovation. Market segmentation helps determine where, within the system, the innovation will be implemented (directly to faculty members or to department heads or deans). The market strategy phase discusses the logistics of the implementation; the communication channels that will be used, how the innovation needs to be adapted to the local audience, etc. The final phase, evaluation, reviews the success of the innovation once implemented (Stirman et al., 2004).

Communication Channels

Rogers' communication channels are discussed on different levels (2008). The different levels for communication channels vary with respect to the stage (the time element of DOI) of the adopter. The conclusions drawn in Rogers are supported by the results found in Stirman (2004). Mass media channels are more appropriate for generating initial levels of knowledge, where interpersonal communications are more critical in the later stages of implementation (Rogers, 2003). The increasing importance of interpersonal channels is also mentioned by Frank et al. through their friends stage in the process (2011). Communication between the researchers and practitioners can be challenging due to their belonging to separate communities, also noted by (Foertsch et al., 1997; Hutchinson & Huberman, 1994; Pundak & Rozner, 2008). The role of communication channels in this study is primarily as a consideration for faculty development and those who help teach instructors about RBIS when developing ways to overcome the barriers discovered here.

DOI and Educational Research

There have been multiple studies within educational contexts that have used elements of the DOI framework. Pundak and Rozner use the DOI stages in an attempt to encourage college staff to adopt active learning (2008). Tabata and Johnsrud used an adapted version of the DOI characteristics which included the original five elements, but also adding *image*, *voluntariness*, and *result demonstrability* (2008); these three elements were added to account for overall social system characteristics that could affect adoption. Borrego, Froyd and Hall investigated the adoption status of RBIS in engineering departments across the country by surveying department heads and mapping with the DOI framework (2010). There have also been a number of explorations into the adoption of RBIS into engineering sciences courses (Borrego, Cutler, Froyd, Prince, & Henderson, 2011; Cutler et al., 2012; J. Froyd et al., 2012; Michael Prince et al., 2012).

Review of Research-Based Instructional Strategies

Over the past several decades, researchers have developed Research-Based Instructional Strategies to help improve student learning in a variety of disciplines. These researchers housed in a variety of disciplines have aided in this work to improve student engagement and learning (Michael Prince, 2004). The effectiveness of different learning strategies and approaches has been studied extensively in fields like education (Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000; King, 1993), STEM education (Mazur, 1997; Meltzer & Manivannan, 2002) However, until recently (Borrego et al., 2011; Cutler et al., 2012; J. Froyd et al., 2012; Henderson & Dancy, 2007; Michael Prince et al., 2012), there has been little evidence that investigates if these research developments are actually being used in the classroom. For example, the National Research Council has called for research-based instructional practices to be used in the classroom (2012).

Nine Research-Based Instructional Strategies (RBIS) were targeted within this study. These RBIS highlight a variety of the RBIS literature. A list of references discussing each RBIS can be found in Appendix E. They can be categorized into four groups, shown in Table 5.

Table 5: Overview of RBIS groups and descriptions of each RBIS

RBIS Groups	RBIS	Description of RBIS as presented in the interviews
Active Learning	Active Learning	A very general term describing anything course-related that all student s in a class session are called upon to do other than simply watching, listening, and taking notes
Group Learning RBIS	Collaborative Learning	Asking students to work together in small groups towards a common goal
	Cooperative Learning	A structured for of group work where students pursue common goals while being assessed alone
	Think-Pair-Share	Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions. After that, calling on students to share their responses
Self-Regulated Learning RBIS	Inquiry Learning	Introducing a lesson by presenting students with questions, problems or a set of observations and using this to drive the desired learning
	Just-in-Time Teaching	Asking students to individually complete homework assignments a few hours before class, reading through their answers before class and adjusting the lessons accordingly
	Problem-Based Learning (PBL)	Acting primarily as a facilitator and placing students in self-directed teams to solve open-ended problems that require significant learning of new course material
Real-Time Assessment RBIS	Concept Tests	Asking multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions
	Peer Instruction	A specific way of using Concept Tests in which the instructor poses the conceptual question in class and then shares the distribution of responses with the class (possibly using a classroom response system or "clickers"). Students form pairs, discuss their answers and vote again.

These nine RBIS were selected for a variety of reasons. All of the investigated RBIS have been discussed specifically within engineering education research and workshops meant to improve student engagement, such as the National Effective Teaching Institute (NETI) (R. Felder, Brent, & Prince, 2012) I also targeted a variety of RBIS: ones developed specifically for large classes, ones that are very general, others that have more specific elements, some that require peer interactions and others that are completed by individual students. I wanted a variety of RBIS to investigate the influence of these varied characteristics on adoption decisions.

Active Learning

Active Learning is a generic term for any activity in the classroom that engages students in the learning process (Michael Prince, 2004). Due to the general nature of this RBIS, Active Learning encompasses each RBIS included in this study and could, therefore, be incorporated into all of the following groups. As a result, Active Learning was given an independent group from the rest of the RBIS.

Active Learning is also probably one of the most studied RBIS with multiple studies looking into its effectiveness (R. M. Felder & Brent, 2009; J. E. Froyd, 2007; Michael Prince, 2004). An example of Active Learning is discussed by Barak who divided an introduction to programming course into three sections using web-based technology; one that was lecture based, one that incorporated partial active learning, and one with extensive active learning. It was found that the students in the partial active learning and extensive active learning sections better met the learning objectives than the lecture section (2007).

Group Learning RBIS

Group Learning (GL) RBIS require students to work together in the classroom. Three RBIS are included in this group: Think-Pair-Share, Cooperative Learning, and Collaborative Learning.

Collaborative Learning is a general term for any group work where students are working towards a shared goal (Barkley, Cross, & Major, 2005). These techniques can be formal group projects or informal classroom activities in which students work with a partner. Shooter and McNeal used Collaborative Learning in their interdisciplinary Mechatronics course to help students meet ABET criterion 3 learning objectives (2002).

Cooperative Learning, an RBIS that falls within Collaborative Learning, can be defined as a structured form of group work where students pursue common goals but are assessed individually (Millis & Cottell, 1998; Michael Prince, 2004). Hsiung divided a planar dynamics course into two sections: Cooperative Learning and individualistic learning (not working with a group). Over time, there was an increased performance with the cooperative learning group on both homework and tests (2012).

Think-Pair-Share is a quick strategy where the instructor poses a problem, has students work on it individually for a short time, has them form pairs and reconcile their solutions, and then calls on them to share their responses (R. M. Felder & Brent, 2009). Byerley used multiple active learning techniques in a thermodynamics course, including Think-Pair-Share, and found an increase in students engagement and project performance (2001).

Self-Regulated Learning RBIS

Self-Regulated Learning (SRL) RBIS begin to transfer the responsibility for learning the content to the students. In this group, students are typically the ones that will seek out the content on their own and the instructor becomes more of a facilitator and resource for the students when they have trouble with the content. Two RBIS are included in this group: Inquiry Learning, Just-in-Time Teaching, and Problem Based Learning.

Inquiry Learning is an instructional strategy in which students are presented with questions to be answered, problems to be solved, or a set of observations to be explained (Kolb, 1984). Coller used Inquiry Learning in his Statics course and found that the electrical engineering students taking the course greatly benefited (as evidence by higher exam grades) when compared to another section that did not use Inquiry Learning (2008).

Just-in-Time Teaching (JiTT) calls for students to individually complete Web-based assignments a few hours before class; then the instructor reads through their answers before class and adjusts the lessons accordingly (i.e. “just in time”) (Michael Prince & Felder, 2006). Cashman and Eschenbach found that JiTT increased student engagement and confidence when implemented in their Introduction to Environmental Engineering course (2003).

Problem-Based Learning (PBL) centers on an open-ended, authentic problem that requires students to identify objectives and needs to find a solution for the problem. In this environment, the instructors take on the role of facilitator rather than source of information while students work in self-directed teams (Michael Prince & Felder, 2006). Reeves and Laffey used PBL in an Introduction to Engineering course and found an increase in the students’ problem solving skills (1999).

Real-Time Assessment RBIS

Real-Time Assessment (RTA) RBIS are founded more on enabling the instructors to quickly assess student learning to address any common misconceptions or challenges the students are facing immediately. Two RBIS are included in this group: Concept Tests and Peer Instruction.

Concept Tests are multiple choice concept questions that use common student misconceptions as distracters (i.e. wrong answers) (R. M. Felder & Brent, 2009). These can be implemented in larger classes through the use of clickers, or similar voting methods, which require students to commit to an answer before discussing the correct answer. Santi used Concept Tests in a geological engineering course to address two common misconceptions (2007). They found a change in student understanding, but were confronted with a number of challenges when developing Concept Test questions of equal difficulties.

Peer Instruction allows students the opportunity to respond to a multiple-choice conceptual question (generally using some sort of classroom response system) and then discuss their response with a neighbor; this is then followed by a repeated response to the question (Pilzer, 2001). Koretsky and Brooks used Peer Instruction in a thermodynamics course for chemical engineering students and found that the quick feedback provided to faculty members greatly aided them in helping students address misconceptions. Also, on simple questions, they found an increase in student knowledge and understanding after completing the peer instruction exercise (2011).

Overview of Methods

Each of the manuscript studies within this dissertation uses a common set of concurrent mixed methods consisting of a national survey of Statics instructors and interviews with Statics instructors at ABET accredited universities in Virginia. This dissertation study is embedded within a larger NSF funded grant exploring the use of Research-Based Instructional Strategies

(RBIS) in engineering sciences classes, which includes Statics (NSF grant # 1097671 and 1037724).

Larger National Science Foundation Grant Methods

The NSF grant used sequential mixed methods (Creswell, 2009c) beginning with a national survey of Chemical Engineering (ChE) and Electrical & Computer Engineering (ECE) instructors teaching engineering sciences courses (thermodynamics, fluid mechanics, heat transfer, circuits, electronics, or introduction to digital logic and/or digital design). The results from this exploratory survey helped inform the interview protocol for the site visit to a large, metropolitan university. The site visit included interviews with both ChE, ECE, and Statics faculty members and administrators. The data collected through the original survey and the first site visit were used to develop a second site visit to a small-rural university, a second survey targeting Statics instructors, and an interview protocol for Statics instructor. An overview of the grant's methods can be seen in Figure 1. The Statics survey and interview protocol were used for this dissertation study.

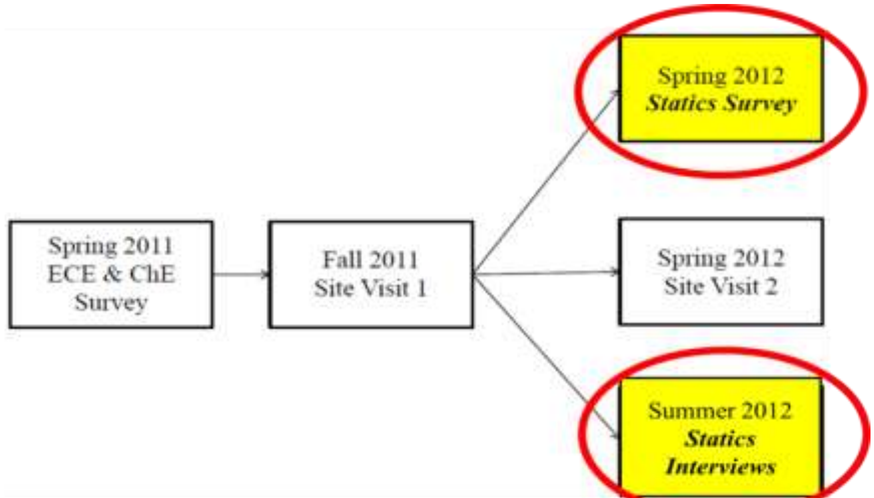

Figure 1: Overall sequential mixed methods of NSF grant; shading indicates dissertation methods

The original proposal focused strictly on ECE and ChE. The Statics elements were explored through a supplement to the original grant, primarily due to my interest in expanding the study to the Statics classroom. Also, the Statics interviews were never included within the scope of the grant. They were added to the research protocol for exclusive use in the dissertation study.

Dissertation Methods

The dissertation study, as an individual study separate from the NSF grant, uses concurrent mixed methods. This design allows qualitative and quantitative methods to be collected and analyzed during the same time period (Creswell, 2009c). Specifically, a concurrent triangulation design was used; where the quantitative (survey) and qualitative (interviews) components were conducted and analyzed separately, but discussed and compared for confirmation and to aid in validating the overall study (Creswell, 2009c). Figure 2 shows the design for the study. The overall study design and the elements within it were reviewed and approved by the Virginia Tech Institutional Review Board (Project number: 10-593).

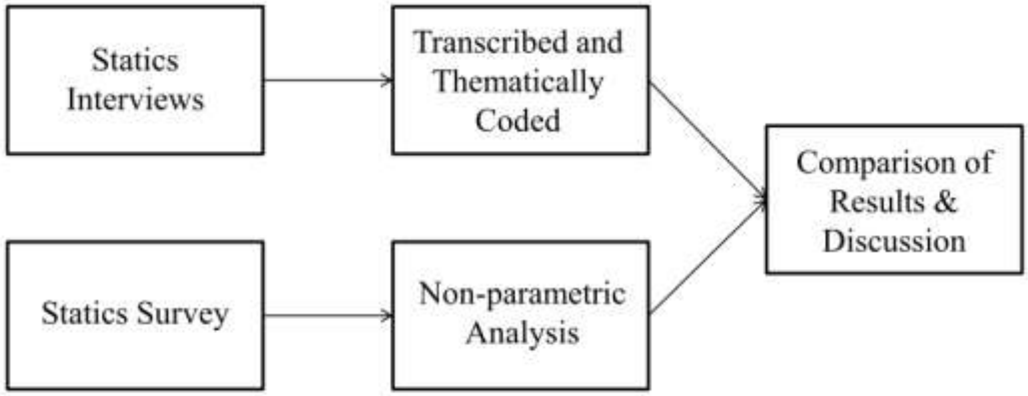

Figure 2: Concurrent mixed methods design for dissertation

Next, the Statics survey (Appendix A) and Statics interviews (Appendix B) will be discussed in more detail including how each method will be used in each manuscript.

Survey

Instrument

The Statics survey is divided into five sections, as shown in Appendix A. The first section asked respondents how recently they had taught Statics. The second asked respondents about their teaching and learning beliefs. The third section asked respondents to estimate the amount of class time spent on different classroom activities. The fourth asked respondents about their level of use and knowledge of nine specific RBIS. The fifth section included demographic information such as gender, rank, and frequency of attendance at teaching workshops.

Validity and Reliability

Establishing the validity and reliability for a survey is a key element of survey research. Validity is defined as "whether one can draw meaningful and useful inferences from scores on the instrument” (Creswell, 2009a). Where the reliability of an instrument refers to the how consistently the instrument produces equitable results (Moskal, Leydens, & Pavelich, 2002).

The Statics survey used in this dissertation was adapted from the NSF grant survey of electrical and computer engineering instructors and chemical engineering instructors (Cronbach alpha of 0.755) (Borrego et al., 2011; Cutler et al., 2012; J. Froyd et al., 2012; Michael Prince et al., 2012), which was based on a previous instrument used to survey Physics faculty’s interest in and use of RBIS (Henderson & Dancy, 2009b; Henderson et al., submitted 2012). Henderson and Dancy discuss the development of the physics instrument, but not the validity and reliability (2009b). A copy of this instrument can be found in (Henderson & Dancy, 2009a).

Since the Statics survey was adapted from the electrical, computer and chemical engineering faculty survey, one aspect of establishing the validity and reliability for the Statics survey is examining the validity and reliability of the survey on which it is based. The electrical, computer and chemical engineering survey was developed for the NSF grant, discussed earlier, by Maura Borrego, Jeffrey Froyd, Michael Prince, and Charles Henderson with the assistance of the Virginia Tech Survey Research Center. The survey was distributed through the Institute for Electrical and Electronics Engineers (IEEE) and the American Institute for Chemical Engineers (AIChE) to encourage a higher response rate (Borrego et al., 2010). The reliability and validity for the grant survey was examined using item analysis and Cronbach’s alpha.

Item analysis can aid in evaluating the validity of an instrument by looking at each item and comparing how a respondent replied to that item in relation to how they responded to the other items on the survey. The bi-serial correlation compares the responses of an individual item to the overall instrument responses indicating the amount of variation between the individual item and the overall variation within the instrument. Most of the correlations should be positive (unless purposefully meant to indicate a negative correlation; reverse scoring) and above 0.3 for a reasonable correlation (Wilson, 2005).Many of the items had bi-serial correlations (discussed in more detail in later section) above 0.3 (calculated by jMetrik software). Items with lower correlations were reviewed and potentially eliminated from the Statics survey. The overall electrical, computer, and chemical engineering instrument had a Cronbach alpha of 0.755 (calculated using jMetrik software), which is an acceptable measure of reliability.

There was suspected response bias for the electrical, computer, and chemical engineering survey which caused a second round of data collection targeting non-respondents. Those who responded during the second round of data collection (late respondents) were compared to the initial round of respondents with limited significant differences.

Where the validity and reliability of the previous instruments contribute to the validity and reliability of the Statics instrument, additional tests should be run to ensure the reliability and validity of this specific instrument.

The internal reliability of an instrument "is based on the notion that the items, or subparts, of the instrument measure the same phenomenon" (Pedhazur & Schmelkin, 1991). To determine the internal reliability of the Statics survey, Cronbach's alpha was calculated as 0.92, which indicates a level of reliability well above acceptable (Pedhazur & Schmelkin, 1991).

Validity was examined from a number of perspectives. Content validity refers to whether or not the content (or variables) that are intended to be measured are in fact being measured (Moskal et al., 2002). In this study, it would mean that the items are accurately gauging the activities completed in the classroom and the instructor familiarity with RBIS. The items in the Statics survey have been, in previous iterations (the previous surveys), reviewed by researchers who have years of experience with educational research methods as well as working in the classroom and with faculty. Any additional changes to the survey were reviewed by these experts to ensure continued content validity within the survey.

The third form of validity is construct validity. Construct validity is defined as "the extent to which an assessment instrument elicits evidence that supports the examination of the nature of the students' [or faculty's] underlying constructs" (Moskal et al., 2002). Generally, this form of validity requires the measurement of variables that are not directly measurable, but may be evident through a student's process or may still be of interest to researchers such as creativity or reasoning (Moskal et al., 2002). To investigate these hidden constructs, a principal component analysis was conducted on Sections 2, 3, and 4 of the Statics survey; the full survey can be found in Appendix A. IBM SPSS version 20 published in 2011 was used to complete the analysis.

Principal component analysis, or factor analysis, can aid in establishing the validity of an instrument by ensuring that the instrument is measuring the intended constructs or factors (Thompson, 2004b).

An exploratory factor analysis was conducted, initially identifying components with an Eigenvalue higher than 1, an acceptable standard of practice (Thompson, 2004a). The overall analysis found 17 separate components, 8 of which had an Eigenvalue greater than 1 (shown in Table A in Appendix C) explaining 63.6% of the variance of the overall survey. It should be noted that Section 3 ranks items from low use to high use as 1-5 and Section 4 ranks items from familiarity to lack of knowledge as 1-5; therefore, for a practical positive relationship, it is expected that these to appear negative in the factor analysis. For example if someone uses Think-Pair-Share in their classroom, they would mark item 4_3 as a 1. They also spend time having students discuss a problem in pairs and might mark 4 or 5 on item 3_2. This opposite coding of the items then results in a negative relationship within the factor analysis.

The items associated with each of the eight components were examined for practical significance. Six of the eight components were found to have high practical significance (followed the literature/framework). The last two components (7 & 8 in Table A) were found to have limited practical significance with scattered connections between the involved items. To more thoroughly investigate the components, I varied the number of components between 2 and 7. According to Thompson, “The purpose of [Exploratory Factor Analysis] is to isolate factors that have simple structure or, in other words, are interpretable. Any thoughtful analytic choices that yield clear factors are justified" (Thompson, 2004a). By limiting the factor analysis to a lower number of components, less variance is explained, but fewer random components are included. By investigating the analysis with several different factors, it was revealed that 6 components explained the highest amount of variability (57.2%) without negligible components that did not offer new insight into the instrument. The six components can be found in Table B in Appendix C.

Overall, the factor analysis provided additional insight into the survey instrument and provided some promising results to show the survey is measuring the intended components (construct validity).

Data Collection

Statics instructors were identified by compiling a list of all accredited U.S. mechanical engineering programs (n = 285). The list also included 7 civil engineering and 4 aeronautical/aerospace engineering programs at institutions that do not offer mechanical engineering. The Virginia Tech Center for Survey Research (CSR) staff contacted each department via telephone with email follow-up to identify the Statics instructors. The protocol included identifying which department was responsible for the course and following up as appropriate. Each instructor was invited to complete the survey via a personalized e-mail signed by Paul Steif and Anna Dollár, established Statics professors and researchers. The survey was administered in fall 2012 to 764 faculty.

Responses were screened to ensure respondents had taught Statics within the last five years and had completed a majority of the survey items. Any participant who did not meet these characteristics was removed from the analysis. Out of the 205 initial responses, 166 Statics were usable.

The Statics survey was sent to 764 faculty members with 166 responses and a response rate of 22%. Of the 166 usable responses, 20% of respondents were female and 62% male (18% did not respond); 13% were lecturers (i.e., not tenure track), 17% assistant professors, 25% associate professors, 17% full professors, and 10% listed their position as other (18% did not respond). The respondents came from a variety of engineering departments or programs: 34% mechanical engineering, 34% civil, 5% aerospace/aeronautical, 2% engineering mechanics, and 7% indicated “other” (18% did not respond).

Data Analysis

Each manuscript uses a different data analysis method to better address the specific research question(s) of that manuscript. Overviews of the techniques used in this study are briefly discussed below and in more depth in the individual manuscripts.

1. Manuscript 1: *What’s Happening in the Statics Classroom*

Manuscript 1 focuses on the activities instructors spend time on in the classroom and was analyzed for descriptive statistics and frequency of responses to the third section of the survey

(Appendix A: Q3). These results were also reflected through the themes that emerges from the qualitative analysis.

2. Manuscript 2: *Dynamic Change in the Statics Classroom*

The quantitative elements of Manuscript 2 focus predominantly on RBIS use and the survey responses (Section 4 of survey found in Appendix B) were used to discover the level of familiarity respondents have with the RBIS. This manuscript was dominated by qualitative results that discussed the barriers instructors faced when implementing the different RBIS (discussed in later sections).

3. Manuscript 3: *Fidelity of Implementation in the Statics Classroom*

Fidelity was operationalized as the percentage of RBIS users who also spent class time on the required critical components. However, between 1 and 5 required critical components were identified for each RBIS. The development of the critical components will be further discussed in Manuscript 3. RBIS users were operationalized as any respondent who indicated that they were currently using a specific RBIS (responded “I currently use it”). A non-user is an instructor who is not *currently* using the RBIS (responded any other way to the item). It was determined that an instructor spent time on an activity if they indicated spending more than 0% of class time on the activity. Due to the varying nature of each RBIS, some activities are meant to only take 1 or 2 minutes of class time which is less than 25% of class time. Instructors were not spending class time on an activity if they spent 0% of class time on the activity. To analyze the discriminating power of the critical component, I used either Chi Square or Fisher's Exact, which will be discussed more extensively in the manuscript.

Interviews

The qualitative component of the current study involves faculty interviews at Virginia universities. The interviews were conducted in person at each university by me and recorded. Each interview lasted between 35 minutes and 2 hours, with the average being approximately 1 hour. The interviews were then transcribed using a transcription service and thematically coded by me.

Interview Protocol

As shown in Appendix B, each faculty member was asked about typical activities that the students complete in their Statics classroom and if and how they used the list of RBIS in the Statics classroom. Faculty members were also asked about how they began using RBIS and any changes they made when implementing in the classroom.

Interview Participants

Participants were chosen through purposeful sampling (Creswell, 2009b) of faculty members teaching Statics courses at universities in the state of Virginia with ABET Accreditation; shown in Table 6. The selection began by identifying universities with ABET accredited engineering programs in the state of Virginia. I then used the university website and their course catalog to identify which universities offered Statics and which departments the course was offered in. Each department was then contacted to obtain the name of the faculty member who had most recently taught Statics. For many departments, this was the same list of faculty members who were contacted to participate in the survey. Each instructor was sent an e-mail invitation to participate in the study. After two weeks, a reminder e-mail was sent and the instructor was contacted by telephone. At least one in-person interview was conducted at each of the identified universities.

Table 6: VA ABET Accredited Schools offering Statics

University	Course Number	Course Title
George Mason University	ENGR 210	Statics and Dynamics
Hampton University	ARC 309	Structures (Architecture)
James Madison University	ENGR 212	Statics and Dynamics
Old Dominion University	CEE 204	Statics
Sweet Briar College	ENGR 205	Statics and Strength of Materials
University of Virginia	MAE 2300	Statics
	CE 2300	Statics
Virginia Commonwealth University	ENGR 102	Engineering Statics
Virginia Tech	ESM 2104	Statics
	ESM 2214	Statics and Mechanics of Materials
Virginia State University	ENGR 210	Statics/Strength of Materials
Virginia Military Institute	ME 201	Statics
J. Sergeant Reynolds Community College	EGR 140	Engineering Mechanics - Statics

Virginia was selected for a number of reasons. First of all, there is a diversity of programs offered within the state as seen in Table 6. There are public and private institutions including an all-women college, a military institute, and two Historically Black Colleges and Universities (HBCUs). There are large and small universities with large/small, old/new engineering programs in varied locations such as in a city or on a land grant; as well as a community college that offers Statics. The second reason was resources. To suitably complete this study, in-person interviews were necessary for the completion of the table activity within the interview. This element was more complex than answering questions and in-person the interviewer was able to see what the faculty members were doing which enhanced the interview data by allowing for additional probing questions to clarify answers. To complete in-person interviews, I traveled to the institutions which required less time and financial resources by driving through Virginia, than flying around the country. However, as reason one states, by limiting the scope of the study to schools in Virginia to save resources, the diversity and richness of the data was not limited.

An overview of participant characteristics can be seen in Table 7. From the interviewer's observation (not reported by participants), the instructors interviewed include one female, one person of Hispanic/Latino, and one of African descent. All others were males of European/Caucasian or Asian descent (e.g., from India or China). Due to the singular nature of having one female participant, each paragraph of the results section will alternate male/female pronouns to protect the identity of the female participant.

In Table 7, the universities were characterized according to the Carnegie classification. An asterisk was added to universities that had a specialized focus such as Historically Black Colleges and Universities (HBCUs), women's colleges, and military institutes. The instructor's letter from Table 7 will be indicated following each direct quote in the results section of each manuscript to add some context to the quotes that are given.

Table 7: Characteristics of Interview Participants

Instructor	Years Teaching Statics	Total Years Teaching	Rank	Class Size	Instructor Degree	Carnegie Classification
A.	> 20	> 20	Prof	> 100	Mech Engr	Very High Research Public
B.	> 20	> 20	Prof	> 100	Mat Sci	Very High Research Public
C.	> 20	> 20	Prof	21 - 40	Mech Engr	Non-PhD granting Public*
D.	> 20	> 20	Prof	Unknown	Civil Engr	High Research Public
E.	> 20	> 20	Associate Prof	>100	Engr Sci Mech	Very High Research Public
F.	> 20	> 20	Associate Prof	>100	Physics	Very High Research Public
G.	6 - 10	11 - 20	Associate Prof	> 100	Mech Engr	Public State
H.	6 - 10	11 - 20	Associate Prof	> 100	Mech Engr	Very High Research Public
J.	6 - 10	11 - 20	Associate Prof	21 - 40	Mech Engr	Non-PhD granting Public
K.	≤ 5	11 - 20	Prof	≤ 10	Elec Engr	Non-PhD granting Public*
L.	≤ 5	11 - 20	Adjunct	21 - 40	Chem Engr	Community College
M.	≤ 5	≤ 10	Prof	≤ 10	Physics	Non-PhD granting Private*
N.	≤ 5	≤ 10	Associate Prof	≤ 10	Mech Engr	Non-PhD granting Private*
O.	≤ 5	≤ 10	Assistant Prof	21 - 40	Mech Engr	High Research Public
P.	≤ 5	≤ 10	Assistant Prof	21 - 40	Civil Engr	High Research Public
Q.	≤ 5	≤ 10	Adjunct	21 - 40	Civil Engr	High Research Public
R.	≤ 5	≤ 10	Adjunct	21 - 40	Mech Engr	Community College
S.	Unknown	Unknown	Adjunct	21 - 40	Architecture	Non-PhD granting Private*

* Indicates that university has a specialization including: women's colleges, Historically Black Colleges and Universities (HBCU), and military institutes

Qualitative Data Analysis

Each interview was recorded, then transcribed by a transcription service. The qualitative analysis for each manuscript varied. Overviews of the techniques used in this study are briefly discussed below and in more depth in the individual manuscripts. A complete listing of the interview codes can be found in Appendix D.

1. Manuscript 1: *What's Happening in the Statics Classroom*

Open coding (Strauss & Corbin, 2008) was used to analyze the transcripts. The codes that are presented as part of the results are those that are directly relevant to answering the research questions; including eleven codes directly discussing different classroom activities, the code addressing the Statics Concept Inventory, and three codes relating to what makes Statics unique. Six of the classroom activity codes were present in a majority of the interviews and will be discussed in the results, the remaining five will be mentioned in the discussion, but were discussed sparingly in the interviews and were not considered “common” activities. The results section is structured to reflect a discussion of these codes using the survey data where appropriate to support the identified codes.

2. Manuscript 2: *Dynamic Change in the Statics Classroom*

The qualitative analysis began with *a priori* coding (Tashakkori & Teddlie, 2003) for the 5 characteristics of Diffusion of Innovation (DOI) as directly referenced by the participants during the table activity. Every time a participant referenced the Relative Advantage, Compatibility, Complexity, Trialability, or Observability of the different RBIS, it was coded with the appropriate characteristic. One of the goals of this study was to gain the instructors’ perspective on these characteristics and how they apply to each RBIS; therefore, only the comments specifically addressing the characteristics discussed during or after the activity were included in these codes.

A second round of coding utilized open coding (Strauss & Corbin, 2008) to explore additional barriers outside of the DOI characteristics. Six codes were categorized within the implementation influences theme: class size, inertia/instructor characteristics, time, university support, outside resources, and student characteristics. Class size and time were expressed by the interview participants when they discussed the DOI characteristics and, therefore, will not be discussed separately in the results. University support and inertia/instructor characteristics were distinctly discussed by a majority of the instructors and will be discussed more thoroughly in the results section. Outside resources and Student characteristics are not discussed here as they were not generally discussed by more than one or two participants and were not discussed in a way that added substantial insight to this study.

3. Manuscript 3: *Fidelity of Implementation in the Statics Classroom*

Manuscript 3 relies heavily on the survey responses and therefore the interview data was used to help support the quantitative results, specifically targeting the unexpected relationships between activities not designated as critical components and a specific RBIS. Fidelity of Implementation was included as an *a priori* code (Tashakkori & Teddlie, 2003) and specifically targeted during the coding process; however, very few passages were mapped to this code, reducing the amount of weight that was put onto the qualitative data in this manuscript.

Summary

This dissertation study focuses on addressing the challenges of connecting research with practice. In Manuscript 1 (Chapter 2), a set of common Statics classroom activities was explored to help communicate these practices to both practitioners and researchers. Manuscript 2 (Chapter 3) explores the level of familiarity Statics instructors have with a common set of Research-Based Instructional Strategies (RBIS) in conjunction with the barriers these instructors see to using RBIS in the classroom. Manuscript 3 (Chapter 4) investigates if Fidelity of Implementation, as developed through K-12, could be applied to the implementation of RBIS in the Statics classroom to evaluate if instructors were using an RBIS, were they using it as the research intended. Finally, Chapter 5 will summarize the findings of all three manuscripts and offer an overview of the implications and future work for the overall dissertation.

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Chapter 2

Manuscript 1: What's Happening in the Statics Classroom: A study of current practices

This manuscript is being prepared for the International Journal for Mechanical Engineering Education. *The journal targets the practices and principles needed for the training and education of Mechanical Engineers.*

The audience for this manuscript is engineering education practitioners. Where the results from this study can aid in advancing research, the primary audience is Statics instructors and other engineering education practitioners in the classroom.

Additional information on the journal can be found at:
http://www.manchesteruniversitypress.co.uk/cgi-bin/scribe?showinfo=ip017

Abstract

To aid in closing the loop between research and practice, this study investigates the current practices within the US Statics classroom. Statics is a foundational course for all mechanics based courses and is central to many engineering disciplines. This study used mixed methods, including a national survey and interviews with Statics instructors in the state of Virginia, to investigate what reported activities instructors are using in their classroom. Results of the study indicate that lecturing was the most common activity, but not the only activity being used in the Statics classroom. Working examples and having students work problems individually and in groups were also very common as reported in both the survey and the interviews. A number of unique characteristics of Statics was also targeted through the interviews. Instructors recognized the importance of Statics courses due to their placement early in the curriculum and the foundational content that is being discussed. This study attempts to aid both researchers and practitioners in understanding the commonalities across universities in how Statics is taught and suggests some ways that both researchers and practitioners can use these results to improve student learning in Statics.

Introduction

Statics is an engineering sciences course that explores basic concepts critical for other mechanics-based courses, such as dynamics or mechanics of materials (Streveler, Litzinger, Miller, & Steif, 2008). Therefore, the concepts that are presented in Statics are the basis for the concepts presented in students’ higher level engineering courses. These concepts, similar to those in all other engineering courses, require students to apply their knowledge of physics and mathematics to solve a physical problem. This focus on student problem solving is not unique to Statics or the field of engineering (T. A. Litzinger et al., 2010).

Although Statics possesses many of the same traits as other engineering courses, it is unique in multiple ways. Statics requires students to learn and apply the concepts of force, couples, equilibrium, contacting bodies and distributed forces, as well as frictional forces (P. S. Steif & A. Dollar, 2005); these are concepts that students have had limited or no exposure to and that will provide the conceptual basis for a number of other classes. Due to the establishment of foundational engineering concepts, Statics is a core, required course for a number of different disciplines. For example, at Virginia Tech nine out of thirteen engineering departments require their students to take engineering Statics (Office of the University Registrar, 2011). Chemical, computer and electrical engineering as well as computer science were the only four disciplines that did not require Statics. The level of Statics understanding necessary to be a mining engineer may not be the same as the level to be a civil engineer, creating the additional challenge of addressing the varied requirements of the different disciplines as well as the cross disciplinary views of students.

These unique characteristics are what allow for this highly influential course to be studied in a pedagogical sense. The combination of the fundamental concepts and the mechanics domain combine to offer a unique opportunity, as teaching thermodynamics offers a unique experience within the fluids domain. Similar to many other engineering science courses, such as thermodynamics or circuits, Statics is a course in which students are first exposed to foundational concepts where misconception and conceptualization research has been conducted (Newcomer, 2010). In addition, because Statics is taught fairly early in the curriculum (mostly sophomore year), it offers an opportunity for an early diagnostic of student problem solving and conceptions (Streveler et al., 2008). It may also be argued that targeting student knowledge and learning in the early Statics course will aid learning and knowledge in the later mechanics based courses; this broadens the impact of studies in the Statics classroom to potentially affecting the overall curriculum.

It is assumed that, like with most other engineering courses, Statics is primarily taught through traditional lecturing in which students listen and take notes. This same assumption is common throughout core engineering courses; however, the engineering education community is attempting to change this standard (Felder & Brent, 2009; Prince, 2004). In order to evaluate these changes, first an assessment of current practices must be completed.

Though Statics is an important course within the engineering curriculum, limited research exists investigating course logistics and teaching styles including the activities instructors are using to teach fundamental principles. The purpose of this study is to explicitly establish some of the common practices within the Statics classroom. To achieve this purpose, the following research questions were investigated.

Research Questions:

What common practices (activities) are being used in the Statics classroom?

What unique characteristics of Statics influence these practices?

Literature Review

Engineering Statics is one of the core courses for many engineering disciplines. Many studies have been published regarding Statics education (Chang & Fourney, 2000; B. D. Coller, 2008; Daniels, 2004; Danielson & Hinks, 2008; Dollar & Steif, 2006; Hanson & Williams, 2008; Haron & Shaharoun, 2011; T. Litzinger et al., 2010; Mehta & Danielson, 1999; Meyer & Land, 2003; Newcomer, 2010; Passmore et al., 2010; PS Steif, 2004; Paul Steif, 2012; P. Steif & J. Dantzler, 2005; P. Steif & A. Dollar, 2005; P. S. Steif & J. A. Dantzler, 2005; Paul S. Steif & Dollar, 2009; P. S. Steif, Lobue, Kara, & Fay, 2010; Venters, McNair, & Paretti, 2012; Venters & McNair, 2010). The next section will discuss the primary researchers in Statics as well as an overview of their contributions.

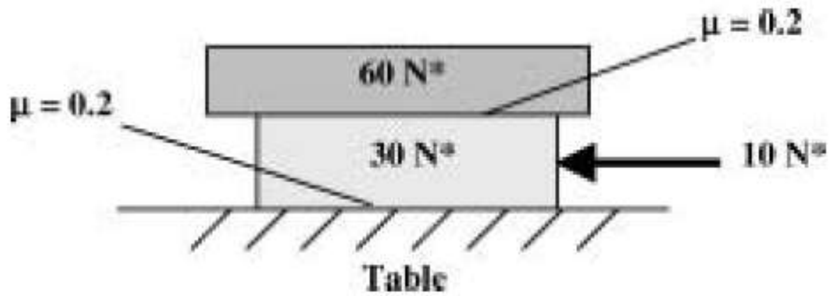
One of the most published researchers in Statics education is Paul Steif from the Carnegie Mellon University. He, along with his collaborator Anna Dollár (Miami University, OH), developed a new way of presenting Statics in the classroom. The course is arranged in such a way that the concepts build “systematically on one another, and [are] addressed entirely in the context of situations where all relevant forces can be perceived through the senses of touch and sight” (2005). To aid in the reorganization of the content, learning modules were developed for implementation. The researchers cited active learning literature and discussed using Concept Tests (Mazur, 1997) as components of the implementation (P. S. Steif & A. Dollar, 2005). In 2006, Steif and Dollár developed additional learning modules for Statics incorporating the reorganization (2005). The learning modules focus on helping students engage in the classroom.

The paper provides enough content detail to influence other Statics instructors' decisions to implement the modules; however, there was little discussion of in-class activities beyond "peer discussion and discovery learning associated with manipulating the object"(Dollar & Steif, 2006).

Steif and Dollár, then, developed an engineering Statics component for the Online Learning Initiative (OLI) (2009). The component contains 5 units with 16 modules. Each module contains a combination of simulations, walkthroughs (similar to a problem tutorial or example), Learning By Doing (LBD) formative tutors, and "Did I Get This?" (DIGT) summary tutorials (Paul S. Steif & Dollar, 2009). The OLI units are online and available to instructors upon request. These modules were used to evaluate student learning gains and self-regulated learning based on pre- and post- completions of the Statics Concept Inventory (SCI), which will be discussed next.

In 2005, Steif collaborated with John Dantzler to develop the Statics Concept Inventory (2005). The article developing the Inventory is one of the most cited pieces of Statics education literature (cited more than 50 times ("Google Scholar," 2011)). The SCI is a 27 item multiple- choice instrument used to measure student understanding of Statics concepts, thus utilizing common misconceptions as distracters (wrong answers) (P. S. Steif & J. A. Dantzler, 2005). An example problem from the SCI is shown in Figure 1 The inventory has been used by many other researchers (B. D. Coller, 2008; T. A. Litzinger et al., 2010; Newcomer, 2010; Papadopoulos, Santiago-Román, & Portela, 2010) as an assessment tool to gauge student conceptual understanding.

Two blocks are stacked on a table. The friction coefficient between the blocks and between the lower block and the table is 0.2. (Take this to be both the static and kinetic coefficient of friction). Then, the horizontal 10 N force is applied to the lower block. (N* denotes newtons.)*



What is the horizontal component of the force exerted by the table on the lower block?

(a) 4 N* (b) 6 N* (c) 8 N* (d) 10 N* (e) 18 N*

Figure 1: Example from Statics Concept Inventory (P. S. Steif & J. A. Dantzler, 2005)

In 2008, Newcomer and Steif used elements from the SCI as warm-up and exam questions to aid in evaluating student learning. Each student was asked to write a brief statement to justify/explain their answer. These “think aloud” explanations were used to compare initial student knowledge to knowledge gained on the final exam. These also allowed the instructor to evaluate student knowledge formatively throughout the semester and adjust his/her teaching to account for student knowledge deficits (Newcomer & Steif, 2008).

Newcomer has published a number of papers individually, many of which use the SCI to evaluate student learning and misconceptions. Newcomer's 2010 conference paper discusses that many students have inconsistent thought processes and methods for completing Statics problems. These inconsistencies indicate only contextual understanding of the Statics concepts that is not transferred to other problems (2010).

There are a number of other authors who have published papers concerning the Statics teaching and learning. Mehta and Danielson discussed 15 different active learning strategies implemented in their Statics classroom. Their overall finding was that the strategies that provided quick feedback were key to student learning (1999). Chang and Fourney integrated a design element into the Statics classroom (2000). Rutz et al. investigated the impact of a variety of online technologies on learning in the Statics classroom; specifically comparing a traditional lecture classroom to a class with video streaming in addition to lecture, web assistance (tutorials) in addition to lectures, as well as the impact of sending or receiving video of the professor in the classroom (as in a distance learning environment) (2003). Hanson and Williams used the explain-a-problem method to evaluate students' self-assessment and communication abilities. Rather than focusing on course content, this study primarily focused on the desired skills and methods acquired by students within a Statics course (2008). Venters and McNair have also continued this work of exploring the impact of writing-to-learn assignments on student understanding of Statics concepts. They have had promising results that show that student score higher on the Statics Concept Inventory after completing the writing-to-learn activities when compared to students that did not complete these activities (Venters et al., 2012; Venters &

McNair, 2010). More recently, Litzinger and colleagues used think aloud protocols and the SCI to evaluate students' problem solving abilities within a Statics course (2010).

Methods

In spring 2012, US instructors who had recently taught Statics (regardless of their disciplinary affiliation) were surveyed. In the summer of 2012, interviews were conducted with Statics instructors at 10 different ABET accredited universities in the state of Virginia.

Survey

The survey instrument was adapted from a previous survey of introductory physics instructors (Henderson & Dancy, 2009; Henderson, Dancy, & Niewiadomska-Bugaj, in press) and a separate survey of Electrical, Computer, and Chemical Engineering instructors for engineering sciences courses (Froyd, Borrego, Prince, Henderson, & Cutler, 2012; Prince, Borrego, Henderson, Cutler, & Froyd, 2012). The Statics instrument was divided into four sections (as seen in Appendix A). The first section asked when the respondents had most recently taught Statics. The second section asked respondents about their teaching and learning beliefs. The third section asked respondents to estimate the amount of class time spent on different activities; this is the focus of this study. The fourth section asked respondents about their level of use and knowledge of nine specific Research-Based Instructional Strategies (RBIS). The final section included demographic information such as gender, rank, and frequency of attendance at teaching workshops.

Data Collection

Statics instructors were identified by compiling a complete list of accredited U.S. mechanical engineering programs (n = 285) as well as seven civil engineering and four aeronautical/aerospace engineering programs at institutions that do not offer mechanical engineering. The Virginia Tech Center for Survey Research (CSR) staff contacted each department via telephone with email follow-up to identify the Statics instructors. The protocol included identifying which department was responsible for the course and following up as appropriate.

Each instructor was invited to complete the survey via a personalized e-mail signed by Paul Steif and Anna Dollár, established Statics professors and researchers. The survey was administered in spring 2012 to 764 faculty. Responses were screened to ensure respondents had actually taught Statics within the last five years and had completed a majority of the survey items. Any participant who did not meet these characteristics was removed from the analysis. Out of the 205 initial responses, 166 Statics were usable.

The Statics survey was sent to 764 instructors with 166 responses resulting in a response rate of 22%. Of the 166 usable responses, 20% of respondents were female and 62% male (18% did not respond); 13% were lecturers (i.e., not tenure track), 17% assistant professors, 25% associate professors, 17% full professors, and 10% listed their position as other (18% did not respond). The respondents came from a variety of engineering departments or programs: 34% mechanical engineering, 34% civil, 5% aerospace/aeronautical, 2% engineering mechanics, and 7% indicated "other" (18% did not respond).

Interviews

The qualitative component of the current study involved 18 instructors interviews at Virginia colleges and universities. I conducted the in-person, in-depth interviews and audio recorded the complete interview. Each interview lasted between 35 minutes and 2 hours, with the average being approximately 1 hour. The interviews were then transcribed using a transcription service and thematically coded by me.

Protocol

As shown in Appendix B, the interview protocol addressed a number of different areas of interest. Each instructor was asked about typical activities that the students complete in their Statics classroom and the influences on those decisions. In addition, instructors were also asked to discuss if and how they used various Research-Based Instructional Strategies (RBIS) in the Statics classroom. Instructors were also asked about how they began using RBIS and any changes they made when implementing in the classroom. The RBIS specific responses will be discussed in Manuscripts 2 and 3.

Participants

Participants were chosen through a purposeful sampling (Creswell, 2009) of faculty teaching Statics courses at universities in the state of Virginia with ABET Accreditation. A list of these universities is provided in Table 1. The goal for the sampling was to complete at least one interview at each identified university (a total of 10 interviews). The selection began by identifying universities with ABET accredited engineering programs in the state of Virginia. I then used the university websites and course catalogs to identify which universities and departments offered Statics. Each department was then contacted to obtain the name of the faculty member who had most recently taught Statics. For many departments, this was the same list of faculty who were contacted to participate in the survey. Each instructor was sent an e-mail invitation to participate in the study. After two weeks, a reminder e-mail was sent and the faculty member was contacted by telephone. A total of 18 instructors were interviewed with at least one from each of the identified colleges, universities, or institutes found in Table 1.

Table 1: VA ABET Accredited Schools offering Statics

University	Course Number	Course Title
George Mason University	ENGR 210	Statics and Dynamics
Hampton University	ARC 309	Structures (Architecture)
James Madison University	ENGR 212	Statics and Dynamics
Old Dominion University	CEE 204	Statics
Sweet Briar College	ENGR 205	Statics and Strength of Materials
University of Virginia	MAE 2300	Statics
	CE 2300	Statics
Virginia Commonwealth University	ENGR 102	Engineering Statics
Virginia Tech	ESM 2104	Statics
	ESM 2214	Statics and Mechanics of Materials
Virginia State University	ENGR 210	Statics/Strength of Materials
Virginia Military Institute	ME 201	Statics
J. Sergeant Reynolds Community College	EGR 140	Engineering Mechanics - Statics

The state of Virginia was selected for a number of reasons. First of all, there is a diversity of programs offered within the state as seen in Table 1. There are both public and private institutions including an all-women college, a military institute, and two Historically Black Colleges and Universities (HBCUs). The universities represent the full spectrum of institutions ranging from small to large, old to new while varying across geographical contexts from urban to land grants campuses. In addition, Virginia contains a number of community colleges that offer Statics. The second reason is resources. Due to the complex nature of this study, in-person interviews are necessary to appropriately conduct the table activity within the interview. This element is more complex than answering questions and being there in-person enables the interviewer to see what the participants are doing. This will enhance the interview data by allowing for additional probing questions to clarify actions and responses. The in-state travel within Virginia to complete in-person interviews required less time and financial resources. However, as earlier stated, by limiting the scope of the study to schools in Virginia does not greatly limit the diversity and richness of the data (other than geographically).

An overview of participant characteristics can be seen in Table 2. From the interviewer's observation (not reported by participants), the instructors interviewed include one female, one person of Hispanic/Latino descent, and one of African descent. All others were males of European/Caucasian or Asian descent (e.g., from India or China). Due to the singular nature of having one female participant, each paragraph of the results section will alternate male/female pronouns to protect the identity of the female participant.

In Table 2, the universities were characterized according to the Carnegie classification. An asterisk was added to universities had a specialized focus such as Historically Black Colleges and Universities (HBCUs), women's colleges, and military institutes. The instructor's letter designation from Table 2 is indicated following each direct quote in the results section.

Table 2: Characteristics of Interview Participants

Instructor	Years Teaching Statics	Total Years Teaching	Rank	Class Size	Instructor Degree	Carnegie Classification
A.	> 20	> 20	Prof	> 100	Mech Engr	Very High Research Public
B.	> 20	> 20	Prof	> 100	Mat Sci	Very High Research Public
C.	> 20	> 20	Prof	21 - 40	Mech Engr	Non-PhD granting Public*
D.	> 20	> 20	Prof	Unknown	Civil Engr	High Research Public
E.	> 20	> 20	Associate Prof	>100	Engr Sci Mech	Very High Research Public
F.	> 20	> 20	Associate Prof	>100	Physics	Very High Research Public
G.	6 - 10	11 - 20	Associate Prof	> 100	Mech Engr	Public State
H.	6 - 10	11 - 20	Associate Prof	> 100	Mech Engr	Very High Research Public
J.	6 - 10	11 - 20	Associate Prof	21 - 40	Mech Engr	Non-PhD granting Public
K.	≤ 5	11 - 20	Prof	≤ 10	Elec Engr	Non-PhD granting Public*
L.	≤ 5	11 - 20	Adjunct	21 - 40	Chem Engr	Community College
M.	≤ 5	≤ 10	Prof	≤ 10	Physics	Non-PhD granting Private*
N.	≤ 5	≤ 10	Associate Prof	≤ 10	Mech Engr	Non-PhD granting Private*
O.	≤ 5	≤ 10	Assistant Prof	21 - 40	Mech Engr	High Research Public
P.	≤ 5	≤ 10	Assistant Prof	21 - 40	Civil Engr	High Research Public
Q.	≤ 5	≤ 10	Adjunct	21 - 40	Civil Engr	High Research Public
R.	≤ 5	≤ 10	Adjunct	21 - 40	Mech Engr	Community College
S.	Unknown	Unknown	Adjunct	21 - 40	Architecture	Non-PhD granting Private*

* Indicates that university has a specialization including: a women's college, Historically Black Colleges and Universities (HBCU), and a military institute

Qualitative Analysis

Each interview was recorded, then transcribed by a transcription service. The transcripts were coded using open coding (Strauss & Corbin, 2008). In general when using open coding, the interview transcripts are coded for initial concepts and deeper meanings. Initial concepts are then abstracted into codes that join similar concepts together through the constant comparative methods (Glaser, 1965). As more and more codes are added and constantly compared, the nature of the categories may evolve or expand to appropriately address the ideas present.

Multiple rounds of coding were performed during the qualitative analysis. The initial round of coding used the interview questions as guides for general themes as the interview questions were guided by the theoretical frameworks and research questions, resulting in 15 general themes. Following the initial round of coding, each theme was examined for specific codes to develop a deeper conceptualization of each theme. New codes were created as needed to address and fully describe each passage. As new codes were created, previous transcripts were revisited to ensure consistency and that every relevant passage was appropriately coded. This iterative process resulted in over 100 different codes. As new codes developed, the interview passages were re-examined to ensure they were matched with the appropriate codes as is consistent with the constant comparative method (Glaser, 1965) . After the codes were fully developed, each interview was read in its entirety to ensure that each segment was coded with the appropriate codes.

Codes presented within the results directly relate to answering the research questions. This including the eleven codes directly discussing different classroom activities, the code addressing the Statics Concept Inventory, and the three codes relating to what makes Statics different. Six of the classroom activity codes were present in a majority of the interviews and will be discussed in the results, the remaining five will be mentioned in the discussion, but were discussed sparingly in the interviews and were not considered "common" activities. The results section is structured to reflect a discussion of these codes using the survey data where appropriate to support the identified codes.

Results

The results section focuses on answering the research questions using a mix of both the quantitative survey results and qualitative interview results. The subsections of the results section are organized with respect to the interview themes to answer the research questions. The first research question (common classroom activities and the Statics Concept Inventory) is addressed, followed by the second research question (unique characteristics of Statics, student challenges, and background of the instructor).

Common Classroom Activities

Both the survey and interview protocol specifically targeted common activities used in the Statics classroom. The list of activities investigated through the survey can be seen in Appendix A. To begin my investigation into the common activities used in the Statics classroom, I looked at the frequency responses for the time spent on each activity, as shown in Figure 2.

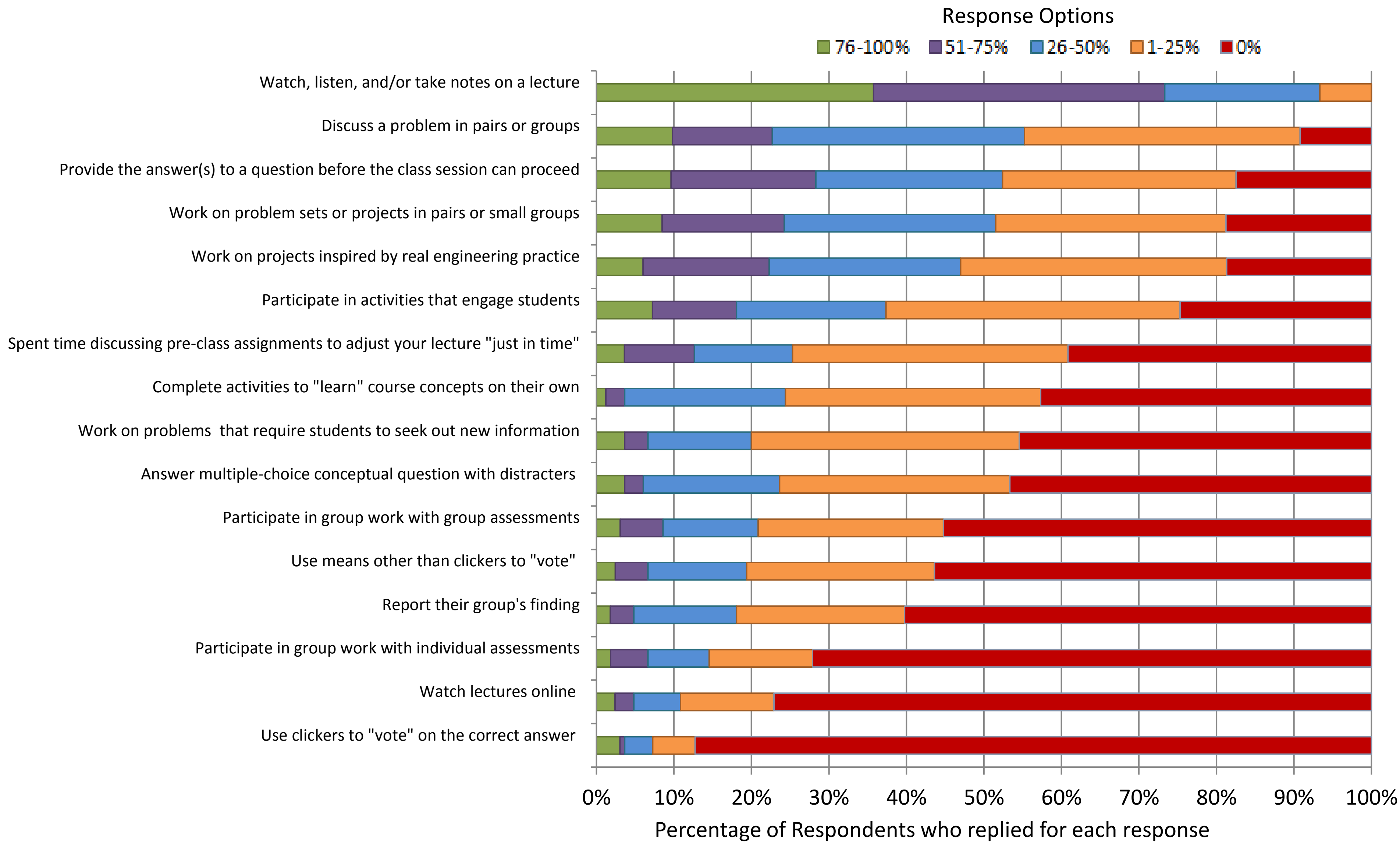


Figure 2: Percentage of respondents that spent time on each activity

Lecturing

In Figure 2, it can seen that all 166 respondents spend at least some class time lecturing. However, less than half spend nearly all (76 – 100%) of their time lecturing in contrast to what is implied in the literature. Lecturing was discussed by the interview participants in a variety of different ways. Most participants discussed their lectures and the different ways that lectures are presented in their Statics classroom. One instructor stated that the lecture was “a step-by-step presentation of notes and step by step through the problems with elementary steps shown,” (R.) where another discussed that:

> [the] typical day in a lecture portion of the course would be me [the instructor] standing in front of the classroom for about three to five minutes talking, basically doing a basic introduction. Usually during that period it’s what we’re going to talk about and how it relates to something that they’ve seen before. (J.)

Another instructor reflected on a number of his peers and their use of the lecture to review material from the book by saying, “When I say ‘go over new content in class,’ it really is…kind of discussing that, the content that’s presented in the reading, and perhaps presenting additional example problems” (B.). Many instructors discussed the lecture portion of class as an opportunity to present new content and work examples. The amount of time spent on lecture varied among the interview participants, from mostly lecture to as little as three to five minutes of lecture dispersed throughout the class session.

Many instructors discussed the tools they use during lecture such as “PowerPoint,” “white boards,” “handouts,” and the slides provided by the textbook publisher. One instructor stated, “I take advantage of the publisher’s slides to enhance the lecture, so they don’t have to read my handwriting and such on the board” (L.). Another faculty member expressed the challenges of using a pre-prepared lecture saying, “I do use PowerPoint to show pictures mostly, but I… usually solve the problem on the board because…since it’s in PowerPoint, there’s no need to write it, so therefore, I’m [the student] paying very little attention to what you’re [the instructor] saying” (H.). Having the pre-prepared lectures may allow the students to watch the lecture, but does not necessarily require them to think about it as they may while copying notes from the board according to this instructor. However, the PowerPoint technology aids in presenting the highly needed visuals for the course. Another faculty member used handouts to provide the needed visuals during lecture saying:

> What I teach has a big graphic content, you know, so especially Statics. So I make handouts that are based on figures from the books. So when I teach my students all have handouts that don’t have a whole lot of text on them but have all the figures from the book, so…If we’re doing a problem, I don’t have to redraw the problem. (N.)

The handouts used by this instructor helped him to present problems as part of his lecture without the challenge of spending time copying the needed visual aids.

Though lecturing was the most prevalent in both the survey and the interviews, it was by no means the only activity instructors were spending time on in the Statics classroom. The next few sections will discuss the various activities that were found to be present in the Statics classroom.

Examples

Another common activity discussed in the interviews was the instructor spending time working examples. Working examples occurred as part of the lecture and through student participation. Spending time having the instructor work examples was not specifically asked through the survey; however, nearly all of the interview participants mentioned working examples in class. Some instructors stated that they "will solve one [provided problem] as an example for" the students (D.), "usually that portion of the class ends with a work example" (O.), or "we [the class] would work sample problems that would explain the new theory" (F.). Other faculty members discussed a progression of examples saying, "The first problem we do, we kind of collaboratively do it, and then the next problem, I play less of a role, and the next problem I play less of a role, and then finally they're doing it on their own" (G.). This instructor reflects a number of other instructors who used examples as the first step to helping students solve problems.

A number of instructors discussed how the examples they were working were not just to demonstrate the content, but to help establish a problem solving mindset or process. One instructor stated:

> I will typically work an example problem to model…the problem-solving approach, so I'll pull in the example saying this group [of students] did this. That was a great example of, you know, sketching the free-body diagram. So the first piece you need to know is we really hit hard on the free-body diagrams. The next piece then is basing your equations off of your free-body diagrams. And then I'll just say 'well, this group did an excellent job of basing, of doing that.' And then there's the problem solving, the mechanics of the problems solving, so usually I'll model that. (J.)

This instructor as well as many of his colleagues discussed the importance of using examples as a way to show students the process for solving problems. Another instructor would solve examples without pre-prepared solutions because "the students get more from the education by actually seeing me construct the solution as opposed to having a prepared solution beforehand" (C.). By constructing the solution in front of the students, his organic problem solving methods are demonstrated for the students allowing them to learn not only the solution to the problem, but the process of how to find it.

Another important element discussed alongside examples within the interviews was incorporating "real world" examples. One instructor stated, "What I do is try to get into a real-life situation, and let's say we're talking about trusses, for example. So I say 'look around. Do you see any trusses here? If a truss is this, do you see any [of] them here?' And they can usually find some around the room" (H.). Multiple instructors referenced the importance of using "real" examples by saying, the students “become much more interested to see, ‘oh, it is a real problem, not only what we draw on the board’” (K.). Another instructor said, “I try and pull in examples, things that I’ve worked on, so I’m not just doing book problems. I find that resonates well with the students” (N.). He followed up by discussing the transition between him working an example and ensuring the students are working on “real world” problems saying, “in Statics we introduce that sort of go into the real world, find examples, realize you have to make, you know, very simplifying assumptions, which is hard for them to do, and then do the analysis. Sort of, I like that whole start to finish of a real problem” (N.). The survey instructors were asked about having students spend time working on projects inspired by problems or situations from real engineering practice. Over 80% of respondents spent at least some time on this activity (Figure 2). The interviews highlight both having “real world” examples presented in class in addition to having students work on ‘real world’ problems.

Working on problems and projects

Working on problems, or more rarely projects, was another common classroom activity discussed in the interviews and the survey. Where the previous section discussed how many instructors used examples as the first step for students to begin working problems on their own, this section will discuss the implementation practices of having students work on problems during class. “Having students spend time working on problems and projects” was examined through several different survey activities as seen in Table 3. Instructors were considered to be spending time on these activities if they responded as spending at least 1% of class time on the activity (responded that they spent: 1-25%, 26-50%, 51-75%, 76-100%; not 0%). A very high percentage (over 80%) of instructors reported spending time on many of these problem centered activities with “work[ing] on problems or projects that require students to seek out new information not previously covered in class" being the activity with the fewest instructors spending time on the activity at 54% (Table 3), which is still over half of the survey respondents.

Table 3: Survey activities that require students to work on problems or projects

Survey items that include student working on problems or projects	Percent of instructors that spent time on activity
Discuss a problem in pairs or groups	89%
Provide the answer(s) to a posed problem or question before the class session can proceed	83%
Work on projects inspired by problems or situations from real engineering practice	81%
Work on problem sets or projects in pairs or small groups	81%
Work on problems or projects that require students to seek out new information not previously covered in class	54%

The interviews highlighted several instructors' reasoning for spending time having students solve problems. When explaining why she requires students to work problems in class, one instructor stated, "learning Statics is the same way a basketball player learns to shoot free throws. You've got to practice. If you don't practice, you're not going to get very good. You've got to practice and make a lot of mistakes so you stop making the mistakes" (A.). Multiple instructors echoed the importance of practicing by working problems as part of the learning process. One stated, "we work several problems so hopefully they're getting to the mind where they can, when they look at it, they can see how simple it is to work it out. And when they first see it, it's like, 'I don't understand, what in the world are you doing?'" (S.). This instructor reinforces his motivation saying,

> [H]opefully, you know, I want to make it so easy for them that, when they get out, you know, when they get out into the professional world and somebody says, 'Well can you

> figure out what's the weight going to be on this end? How much weight do we need to keep it in equilibrium?' They say, 'Oh, sure, yeah, you do this right here?' (S.)

This instructor wants students to be familiar with the problem solving process so they will be comfortable with the material and as they move forward in their careers they will be prepared. He sees working problems in class as a way to help students obtain that comfort level.

Instructors also highlighted the importance of having students work problems in class, not just as homework. One instructor discussed some of the benefits of having students work problems in class, as opposed to as homework, saying,

> We'll have a set of two or three problems which those students will work on in groups, and I'll kind of roam around the room, asking a couple of students questions or they'll ask me questions as we go along…So I'm just going around and around and trying to see how they're doing. It allows me to see if there's, kind of, common misconceptions, if they're all kind of heading down the same wrong road. (J.)

This instructor emphasized the importance of students working problems in front of him so she could check their work and offer quick feedback on their processes. Multiple instructors mentioned walking around to address student questions while students worked on problems. Another instructor simply stated, "I will give assignments, class assignments, to the students and

I'll walk around and see how they are doing" (P.). The feedback that the instructors can provide while students are in class was mentioned by multiple instructors as an important part of the problem solving activity.

Having students solve problems in class was a very common classroom activity discussed in the interviews and surveys. The surveys revealed a promising number of instructors who spent some class time having students work on problems, where the interviews offered specific examples of how these problems are integrated into the classroom and their motivation for using these particular activities. In addition to solving problems and working individually, working in pairs or groups was also highlighted in both the survey and interviews

"Discuss[ing] a problem in pairs or groups" was not highlighted as often in the interviews as working on problems. A few instructors mentioned having students discuss certain concepts or processes while working through problems. One stated, "We take the classroom time to have that collaborative session where the students are working with each other, hopefully asking each other good questions about how to approach a problem" (G.). This instructor is encouraging students to discuss the problem in addition to going through the process of solving it. Pure discussions were not reflected nearly as frequently as working the problems in the interview; however, this activity was used by nearly 90% of survey respondents (Table 3). One instructor did mention having discussions with the entire class after having the students work on a problem asking questions such as, "what is the common approach to solving the problem? What are the things that are common between this group and this other group? And why did you approach it that way? What was your thinking?" (J). This instructor was "try[ing] to pull them [the students] into the conversation and piece together a nice, a solid approach to solving a Statics problem" (J.). This again brings in a discussion about the process of solving Statics problems in addition to working through the problem.

Working in Groups

Similar to the survey item about having students "work on problem sets or projects in pairs or groups," one interview participant discussed a common activity in her Statics class, which she called "group problem solving." She says, "the students will go and try to apply the concept that I just tell them briefly, and even if they don't get it right, the idea is to, first of all, they have to pay attention because they have never seen it…And this way they could talk to each other" (H.). Her reasoning for using this activity was, as she said, "from my years of teaching Statics, I think this is what I see provides the best results" (H.). Another instructor discussed how his students work on problems in class saying, "They'll work in groups of typically three or four, and they'll work their way through two or three follow-up problems that are designed to kind of, the first one would be a more close to the example. Then the next one would add maybe a layer of difficulty or that sort of thing" (O.). To explain his motivation for using this activity in the classroom, he said, "The reason we started doing that is because what we noticed was … if we did more of the pure lecture approach, the students would smile and nod and then have absolutely no idea how to do the homework. So getting their hands dirty a little bit in class is kind of key" (O.). Ultimately, over 80% of the survey respondents spent time having students work on problems and/or projects in class and the interview participants highlight key features of how they use this activity in their classroom and their motivations behind it.

In addition to solving problems, some instructors provided additional opportunities for students to work on teams or in groups. The survey asked specifically about structured group work with two items. Less than half of the respondents (44%) spent time having students "participate in group work for which they earn the same score as every other member of the group" and even fewer (28%) spent time having students "participate in group work for which the assessments are designed so that individuals may earn different scores for their work on the assignment." Grading was generally not discussed as part of the group classroom activities in the interviews as it was specifically in the survey; however, a number of instructors discussed having students work in pairs or on teams. One instructor stated, "I'll give them a homework assignment where they have to, they pair up, and they have to go out and find examples of different kinds of loading, take photos of it, and then submit a document that says, you know, 'here we found this'" (N.). Another stated in more general terms, "Every day there's a problem-based part, a teamwork, collaborative, problem-solving kind of part to the class" (G.).

Reviewing homework

Another way in which instructors discussed having students solve problems was through homework. This study was not specifically targeting the homework practices of Statics instructors; however, multiple instructors discussed using class time to review the homework. The survey inquired about having students "spend time discussing pre-class assignments which helped [the instructor] re-evaluate student learning and adjust [their] lecture 'just in time'", which 61% of the survey respondents indicated spending time on (Figure 2). Multiple interview participants discussed having students turn in their homework at the beginning of lecture, and a few discussed responding to common misconceptions after the homework had been graded. However, no instructors discussed having students turn in homework before class with enough time to be reviewed and adjust that week's lecture. One instructor stated, "After we graded the homework, most of the common mistakes made by the students, we will try to respond to," (D.) while another stated the students "would have tried some problems from the book, and I would ask them questions about what they tried and where they got stuck" (M.). Yet another instructor discussed responding to homework by saying, "depending on how many problems were assigned, and when they were due, we would go over all of them, the problems, or perhaps specifically the problems that students might ask questions about" (E.). Reviewing the homework and addressing challenges students faced was discussed by several interview participants.

Multiple Choice Questions

The survey investigated how often instructors spent time having students "answer multiple-choice conceptual question with distracters (incorrect responses) that reflect common student misconceptions." Just over half (53%) of survey respondents indicated spending time on this activity. Very few interview respondents discussed this type of activity. One explained, "When we do the lectures now some of it is multiple choice questions, and we throw in wrong answers to see if they're going to pick up on that, which is common mistakes like rotation is clockwise, counterclockwise…they tend to forget that" (R.). The multiple choice questions were commonly probing basic conceptual understanding of the topic covered during lecture or the reading the students were meant to complete before coming to class. This was not an activity commonly discussed by a large number of participants, but a few did discuss this as an important part of their classroom experience.

Statics Concept Inventory (SCI)

As discussed in the literature review, the development of the Statics Concept Inventory (SCI) is one of the most cited Statics articles. Due to its popularity in the literature, the SCI was specifically inquired about in both the survey and the interview protocol. Figure 3 summarizes respondents' familiarity with the SCI. A large number (n=114; 69%) of survey respondents had at least some familiarity with the SCI, with 15% (n = 25) currently using the SCI in their classrooms.

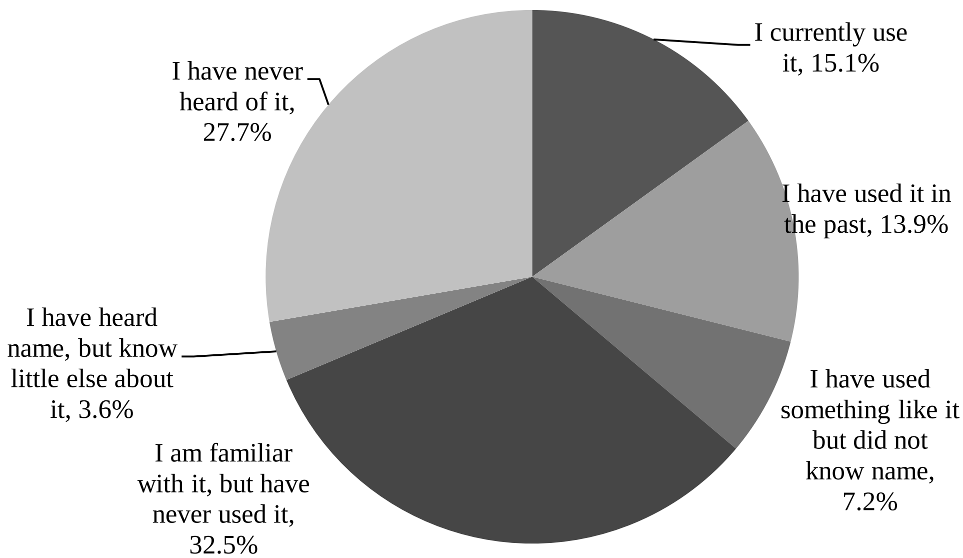


Figure 3: Survey respondents' familiarity with the Statics Concept Inventory

The interview participants had varying levels of familiarity with the SCI ranging from using the SCI in their classroom to having never heard of it. Only one interview participant indicated currently using the SCI in the classroom stating that she used it as a "post-assessment" for accreditation and department assessment committees. The instructor had some challenges using the SCI to measure student success in the class saying, "I think it [the SCI] tests basic Statics concepts, but I think what we're trying to do is get a little more into the problem solving aspect of it and the complicated nature of it. And I'm not sure that that captures it" (J.). Other instructors indicated that in the past they had used the SCI as an assessment or a point of comparison across universities (i.e. how do our students compare to the "norm"), but not as a classroom activity.

A majority of the interview respondents had not heard of the SCI or were only familiar at a surface level ("I've heard the name" or "I've heard of it, but I don't use it"), but when asked, nearly all of the instructors felt that the SCI was a "good idea" and that they would be interested in potentially integrating it into their classroom. One instructor discussed the benefits of using the SCI would be to:

> break students' thinking. Because in order to bring in new knowledge, they're going to have to adopt new concepts, which means they're probably going to have to break some old concepts about how things work… [The SCI] would allow me to ask additional concept, concept-type questions and see if they're on track or not and help them see that that doesn't work but this does. (L.)

Others indicated they would consider using the SCI as a quiz, a set of "canned" examples, or as a longitudinal tracking system for student understanding in the class.

Unique Characteristics of Statics

Each Statics instructor was asked what made Statics different from the other courses they taught. Their responses resulted in five separate codes that will be discussed in the following subsections.

Statics Content

A number of Statics instructors discussed the Statics content making it different from other courses. This was generally discussed with respect to the foundational aspect of the content and the additional skills outside of the specific content, both of which students need to be successful in future courses.

The importance of establishing this basic knowledge of the concepts was discussed by one instructor who said, “So much of [Statics is] developing some of that base knowledge, right?...[S]tatics gets used in a lot of places; just the ability to draw a free body diagram, ability to write equilibrium equations. Now, it gets used a lot in mechanics, and even, you know, more advanced phases of mechanics” (O.). Another instructor emphasized that part of his responsibility as an instructor was to convince students of the fundamental level of the knowledge they were covering. He said, “I’m trying to help them see the world of Statics as not that complicated, it really comes down to balancing forces and moments” (L.). Working with the fundamentals of a subject is discussed in the literature as an important part of engineering sciences courses (Streveler et al., 2008), as was echoed by the interview participants.

An additional challenge can come from the basic level of knowledge needed to teach Statics. Many instructors discussed that one of the challenges and unique attributes to Statics was the simplicity of the material. One instructor stated, “I think what makes [Statics] different, and this is going to sound obvious, but maybe it’s not, is that they don’t know Statics” (O.). She went on explain that the challenge of the students not knowing Statics is

> a lack of first principles of engineering, and I would tend to compare it to if you can speak a language, expanding your vocabulary versus learning the language in the first place…learning how to properly conjugate things is one thing, but learning how to say basic words is another, and that’s kind of where they’re at (O.).

Statics courses are meant to help students begin their conversations as engineers. Similarly, other instructors discussed that there is a challenge when teaching simple subjects saying, “Sometimes the course is very easy for me but it’s difficult for them, so teaching very easy things to people is not an easy job…Teaching difficult things is much easier to teach… Advanced courses I can teach much easier. But Statics is not really a difficult course” (K.). Again, part of Statics is starting a conversation when the instructor is fluent in Statics and the students are just learning the fundamentals.

In addition to presenting foundational content, several instructors also emphasized the importance of the non-content-specific skills that students begin to learn in Statics. One instructor commented, “Statics is the basic first engineering mechanics class that they’re going to get. And so, one of the things that we try to do in that class is we try to teach them how to solve a problem…how to present that solution” (C.). Another instructor discussed that “in Statics, it seems like there’s not that much…content, I guess, so that the skill of doing problems, you can use just massive amounts of class time for that” (M.). The importance of Statics lies in the skills around solving the problem in conjunction with the content that makes Statics unique. Another instructor stated, “the other challenge in Statics is that we’re introducing them to a lot of tools” (L.). It’s not just equations that students are responsible for learning; they are being introduced to the tools and techniques for applying the equations and tools to solve problems, which is a new challenge for them.

Curriculum

As discussed previously, Statics is a prerequisite for nearly all mechanics-based courses. This offers a unique niche for helping to prepare students for these future courses. A number of instructors discussed the importance and influence of Statics within the curriculum. One instructor stated, “Statics is the core class for our…engineering students. Actually, that’s the first…engineering class that they take in the department…We just make sure that the students have a basic background to move on, so we give a high emphasis on that class” (P.). Another instructor emphasized the importance of Statics at the front of the curriculum saying, “Statics is maybe a little different in it is probably the first real engineering course the students have, so the students are maybe still a little more immature and still a little more unready. My other classes, they’re maybe a little more used to doing the kind of things we do in engineering” (F.). The idea that Statics is the students’ first exposure to engineering was echoed throughout the interviews.

Due to Statics' position at the front of the curriculum, it is important that students master the material because it is needed for future courses. The impact of the future courses was emphasized by multiple participants. One instructor stated, "Statics is just the beginning salvo really of a mechanical engineers' understanding of why things break, why you have to make things of certain sizes that carry the loads. And so, it's not just Statics" (A.). She went on to emphasize that "all these other courses start out that you understand the precepts of those six laws in equilibrium" (A.). Another instructor echoed the importance of ensuring that Statics is taught well because it is so important for later classes saying,

> I think the Statics class needs to have the best, brightest instructors in that class, and also it needs to be rigorous, the class, because the student has to grasp that material to proceed… Because just about every class after that, including thermodynamics, has some need for them to grasp the Statics material. (C.)

Due to Statics' position in the curriculum, multiple faculty members recognized its importance and the unique position they are in to ensure the students understand this foundational knowledge.

Problem Solving like an Engineer

As discussed already, Statics is unique due to the foundational concepts being taught at the beginning of the curriculum. Another unique aspect, which is influenced by the content and

Statics' place in the curriculum, is that Statics is when students are being challenged to begin to "think like an engineer" or to "problem solve like an engineer." One instructor commented,

> Statics is a marking of the… first engineering class a lot of these students have had…It's kind of that transition point between the, I want to say general, the building, you know, their chemistry classes and their calculus classes and their physics class where it's much more, you know, everyone should be working at the same way to a much more open-ended, and you can take a truss apart anywhere you want and then try to make that decision of well, if I can do anything, what's the best thing to do, which is a, you know, a big difference between calculus and engineering classes in general. (Q.)

The decision making that is required for engineering classes is first taught in Statics helping to teach students to think and solve problems with an engineering mindset.

The interview participants observed a number of unique aspects of Statics that influence how they teach the course. These aspects include the fundamental, simple content of the course, Statics' location at the beginning of the curriculum, and being the initial exposure to engineering problem solving.

Discussion

From both the survey and the interviews, the results show that while lecturing is the most prevalent activity in the Statics classroom, it is by no means the *only* activity. Other common activities include presenting examples and having the students work problems both individually and as a group. Where other activities were explored in the survey and discussed in the interviews, they were not done in a way that was consistent or common across participants. Additional activities that were discussed in the interviews include: having students participate in an online blog, probing students to ask questions, completing quizzes (both multiple choice and open response), completing writing assignments, and providing time for students to meet with the instructor one-on-one.

The additional activities that were probed through the survey can be seen in Figure . These activities had fewer respondents who spent time on the activities, but there were no activities that were reported with zero respondents spending any percent of time on it. One example was the activity having students work on problems that require students to "seek out new information," which was not explicitly discussed in the interviews, though 54% of survey respondents indicated spending class time on this activity (Table 3). A few interview participants discussed having students work on projects that required the students to make assumptions, but not directly seek out previously unknown information.

The variety of activities that are being completed in the classroom reflect the varied contexts that Statics is being taught in across universities and the varied teaching practices of the instructors teaching the courses. Several instructors did not take Statics as undergraduates while others used the concepts learned in Statics while working in industry creating very different approaches to teaching the course. Some universities had multiple sections of Statics with a common curriculum across all sections where other had one small section that was a combined class including Statics and Mechanics of Materials or Statics and Dynamics. Also, the number of contact hours required for the course varied across universities from 3 to 5 and the structure of those hours varied from completely “lecture” based to “lecture and lab or recitation” based. These varied contexts and backgrounds of the instructors fuel the diverse set of activities that are happening in the classroom, but there is still a commonality of the lecture, examples, and problem solving activities across these contexts.

Though technology was not specifically targeted in this study, multiple instructors discussed the role technology played in their classroom. From basic PowerPoint to more advanced online blogs, multiple instructors discussed the changes they have made to their teaching to try and incorporate new technologies. In addition to presenting with technology (PowerPoint, DyKnow), a few instructors used them to incorporate examples by using computer modeling software.

One catalyst for the use of technology and other activities in the classroom was the activities or technology provided or supported by the course textbook. The influence or role of textbooks was also not specifically targeted by this study, but was discussed by a few instructors. Typically, the textbook was mentioned when it influenced how the instructor taught the course. For example, several instructors brought up activities that were provided by the textbook such as “group problem solving,” “multiple choice question,” “project-based question,” or “reading quizzes” that they integrated into the course. Using textbooks as a catalyst for dissemination for research innovations or change in not only the Statics classroom, but classrooms in general is a suggested path for future research and dissemination efforts.

The Statics Concept Inventory is an excellent tool developed through research to aid those who teach within the Statics classroom; however, it has not been widely acknowledged, much less adopted, by the Statics instructor community. In addition to raising awareness by continuing conversations about the SCI, encouraging broader used of the SCI could aid in its implementation. One suggestion for further dissemination of the SCI is to provide training or tutorials for how to use this tool in the classroom. Many of the instructors only see this as an assessment tool, but it could also have an impact as a classroom activity to engage students throughout the semester instead of only at the end of the semester.

Conclusion

While answering the first research question, there is promising evidence that Statics instructors are evolving their practices to include a wider array of activities beyond lecturing; lecturing is still the most common activity occurring in the Statics classroom. Using examples and working problems both individually and in pairs or groups are also common to many Statics classrooms. Answering research question two, the results showed that instructors recognize the important role that Statics can play in the curriculum due to its placement at the beginning of students' academic careers and the fundamental content that the course covers. Additionally, many students are first exposed to the application of math and physics to solve a problem in this course, enhancing its importance.

Implications for Practice

One of the key implications for this study is establishing a base-line analysis of what activities are common in the Statics classroom. Research helps to discover effective teaching practices that should be used in the classroom; however, it is challenging to document the adoption of research being used in the classroom. This study is meant to aid both researchers and practitioners to ensure the most effective teaching practices are being used in the Statics classroom.

For researchers, this study helps to establish what is happening in the Statics classroom to help show the activities that have already gained acceptance by instructors and to show the gaps that research can potentially fill. This study is meant to help create a connection between research and practice, so one informs the other resulting in the best practices being used in the classroom.

For practitioners, this study hopes to start a conversation across universities by showing that, even though university contexts vary, there is still a commonality in the way most instructors think about and teach Statics. It is the hope of this researcher that instructors from different universities can use this study as a way to begin a discussion with their Statics colleagues to learn from each other to help improve student learning in Statics.

Future Direction for Research

In the future, this research should be expanded to include classroom observations to ensure what instructors are reporting as happening in their classroom is actually happening. Additionally, it would be interesting for future work to expand to specialized universities such as highlighted teaching-focused universities that are known for their innovative student-centered approaches to teaching or those that are highly research focused and known for their challenging curricula.

This study helps to establish a baseline of classroom practices for Statics. Future work should expand on this and investigate how specific research-based instructional strategies are being used in Statics in addition to the classroom activities. To aid in changing the practices in Statics, the barriers instructors face when attempting to implement new practices in their classrooms should be investigated.

Another possible direction for future work is for similar studies to be conducted in other common foundational courses to help both researchers and practitioners to better understand the overall picture of the practices in those fields including similarities and differences. These studies should be done regularly to increase the probability that researchers understand the current practices in the classroom and that practitioners are kept abreast of current theoretical approaches to enhance student learning. In a few years, this study (minimum of the survey) should be repeated to investigate any changes that have occurred over that time.

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Chapter 3

Manuscript 2: Dynamic Change in the Statics Classroom: An investigation of faculty perceptions of barriers to adoption of innovative teaching practices

This manuscript is being prepared for the International Journal of Engineering Education. *This journal provides an international forum for scholarly engineering education research.*

The audience for this study is both researchers and practitioners. One of the aims of this paper is to bring researchers and practitioners into one consistent conversation that helps both communities and is, therefore, written for both.

Additional information on this journal can be found at: http://www.ijee.ie/

Abstract

There has been a recent call in engineering education to close the gap between research and practice. One way to bridge this gap is through the implementation of Research-Based Instructional Strategies (RBIS) into engineering classrooms. To help aid in this effort, the current study uses mixed methods to investigate the familiarity of US Statics instructors with nine RBIS and the barriers Virginia Statics instructors face when implementing RBIS into their classroom.

Using a national survey of Statics instructors, it was found that a majority of instructors indicated minimal awareness of RBIS, but a number of instructors either had not tried RBIS or had discontinued use after trying an RBIS.

Through in-person interviews with Statics instructors throughout the state of Virginia, the Diffusion of Innovation (DOI) characteristics of an innovation (the Relative Advantage, Compatibility, Complexity, Trialability, and Observability) were all found to be present barriers to RBIS adoption. The individual Statics instructors carried separate opinions of the Relative Advantage of the different RBIS. Many instructors felt that RBIS were aligned with how they felt learning happened, but there was generally one RBIS group that was not compatible for each respondent. Trialability and Complexity were identified as significant barriers to implementation, with many instructors citing time constraints, class size, and characteristics of the different RBIS groups in their reasoning. Observability was the most broadly discussed barrier, with the instructors not generally associating the barriers with a specific RBIS, but a lack of data, knowledge of evaluation methods, and a uniform objective for RBIS.

In addition to the DOI characteristics, university support was often discussed as neither a support nor a barrier for RBIS use. However, university Centers for Teaching and Learning were cited by a number of faculty members as positive influences on using RBIS in their classrooms. Also, the idea of instructor inertia developed through the interviews, indicating that one of the biggest barriers to instructors not using RBIS is that they have not used them in the past and they do not wish to change their teaching practices.

Introduction

As articulated by the American Society of Engineering Education (ASEE) *Phase 1 report: Creating a Culture for Scholarly and Systematic Innovation in Engineering Education* (Jamieson & Lohman, 2009), there has been a strong focus in the engineering education research community to ensure a complete cycle connecting research to practice and vice versa. Where engineering education grew out of engineering classroom practices, with the call for rigorous engineering education research by the *Journal of Engineering Education* (Lohman, 2005) and the development of engineering education as a research field, a gap developed between the research and the classroom practices. One of the ways to bridge this gap is through the use of Research-Based Instructional Strategies (RBIS) in the engineering classroom.

Over the past several decades, researchers have developed RBIS to help improve student learning in a variety of disciplines. However, until recently (Borrego, Cutler, Froyd, Prince, & Henderson, 2011; Cutler, Borrego, Henderson, Prince, & Froyd, 2012; J. Froyd, Borrego, Prince, Henderson, & Cutler, 2012; Henderson & Dancy, 2007; Michael Prince, Borrego, Henderson, Cutler, & Froyd, 2012), there has been little evidence that demonstrates if these research developments are actually being used in the classroom. Recently, the National Research Council has called for research-based instructional practices to be used in the classroom (2012). Contributing to this investigation of the adoption of RBIS, this study aims to investigate the barriers that Statics instructors face when adopting RBIS for their classroom by answering the following research question: What barriers do faculty members perceive to the adoption of RBIS?

Literature Review

The focus of this literature review is twofold. First, the dissemination literature will be discussed as it relates to the Diffusion of Innovation (DOI) framework (Rogers, 2003) used in this study exploring the major elements of DOI including: the *innovation*, *time*, and *communication channels*. There will also be a brief discussion of research studies that have used DOI in an educational setting. The second focus offers an overview of the Research-Based Instructional Strategies (RBIS). The RBIS have been grouped into four groups based on similar attributes (Active Learning, Group Learning, Self-Regulated Learning, and Real-Time Assessment). Each RBIS will be described with a brief overview of the literature that has been used to establish it as an effective instructional strategy.

Dissemination Literature

Though many theories for dissemination and diffusion are discussed throughout the literature, one of the most influential is Diffusion of Innovation (DOI) (Rogers, 2003; Stirman, Crits-Christoph, & DeRubeis, 2004), which was used to guide this study. The reasons Diffusion of Innovation (DOI) was chosen for this study are listed in Table 1. The first reason is that Diffusion of Innovation is one of the most widely used and well established frameworks for dissemination research. It has been used in multiple studies within educational settings (including STEM education and engineering education), as well as in theses and dissertations (Johnson, 2001; Watson, 2007). Within these studies, there have been very few contradictory findings, providing additional validity and support for the framework. Many of the other frameworks share multiple components with DOI and some were even based on the DOI framework. However, the other frameworks do not offer a complete picture of the overall diffusion process. Many focus on one element: the process, communication, or the attributes of the innovation, but DOI offers a framework for each of these elements as well as how they fit together. The general overview nature of DOI was one of the reasons it was chosen, since limited work has been done within the engineering education field, there is not a specific theory that would be more applicable for this particular study. Though in recent years, DOI has been used as the primary theory for studies investigating RBIS use in the classroom (Cutler et al., 2012; Henderson, Dancy, & Niewiadomska-Bugaj, submitted 2012).

Table 1: Reasons for choosing Diffusion of Innovation Framework

Reasons for Choosing DOI
- Widely used and well established - Shares components with other frameworks - Basis for many other frameworks - Offers a complete picture, not just one aspect

Diffusion of Innovation has four major elements: *innovation*, *communication channels*, *time*, and *social system*. Each element is important to examining the overall phenomenon of innovation adoption; however, this study focuses on the barriers Statics instructors face when deciding to adopt specific educational innovations. However, this study is focusing on the characteristic of the innovations that instructors perceive as barriers and will not be discussing the other elements.

Characteristics of the Innovation

Since the focus of this study is on barriers to adoption, the characteristics of the innovation play a very important role. According to Rogers, *innovation* can be characterized by traits that increase the rate of adoption, such as: (1) *Relative Advantage*, (2) *Compatibility*, (3) *Complexity*, (4) *Trialability*, and (5) *Observability* (2003). Due to their influence on the rate of adoption, these characteristics can be viewed as benefits that increase the rate of adoption, or barriers that hinder the rate of adoption. As part of the data collection for this study, interview participants were asked to use the DOI characteristics to evaluate Research-Based Instructional Strategies (RBIS). The definitions (both Rogers and those provided to participants) are provided in Table 2.

Table 2: Diffusion of Innovation Characteristic Definitions

Characteristic	**Definition provided to participants**	**Rogers Definition (2003)**
Relative Advantage	The benefit of doing [an RBIS] over lecturing	"The degree to which an innovation is perceived as better than the idea it supersedes"
Compatibility	The similarity to how [an instructor] thinks learning occurs	"the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters"
Complexity	How hard it would be to use [the specific RBIS]	"the degree to which an innovation is perceived as difficult to understand and use"
Trialability	How easily [the instructor] could try [an RBIS] before using it	"the degree to which an innovation may be experimented with on a limited basis"
Observability	How easy it is to see how well [an RBIS] is working	"the degree to which the results of an innovation are visible to others"

These characteristics are unique to the DOI framework, but other dissemination literature has developed similar, but different characteristics for innovations; these will be discussed next.

In 1993, Hutchinson and Huberman composed a literature review of dissemination literature. Within this review, they proposed seven predictors of successful dissemination: accessibility, Compatibility, quality, redundancy, linkage among users, engagement, and sustained interaction.

Accessibility relates to how available the innovation material is to potential adopters. *Compatibility* relates to how the innovation fits into the actual application or “real world.” *Quality* refers to evidence that the innovation will work, or the evaluation and validation showing the innovation will be successful. *Redundancy* refers to ensuring that the potential adopters are exposed to the innovation through multiple communication and dissemination channels. *Linkage among users* refers to ensuring interpersonal communication among the users. By providing opportunities for the users to engage with the new program will help to encourage *engagement* to increase the chances of success. The final predictor is *sustained interaction* described in extended detail compared to the other six predictors. Sustained interaction ensures the adopters will have continued access to the researchers or change agents throughout the implementation process. Hutchinson and Huberman’s predictors are comparable to Rogers’ characteristics mentioned earlier as shown in Table3.

Table 3: Comparison of Hutchinson & Huberman’s predictors to Rogers’ characteristics

Hutchinson & Huberman’s Predictors	**Rogers Characteristics**
Accessibility	Elements of Complexity
Compatibility	Compatibility
Quality	Relative Advantage and Observability
Redundancy	Discussed as part of Communication Channels
Linkage among users	Discussed as part of Communication Channels
Engagement	Trialability
Sustained Interaction	Discussed as part of Communication Channels

More recently, Frank and colleagues began with a theoretical framework that had been used to examine the diffusion of computers within school systems, but ultimately developed their own framework for how teachers gain knowledge of an innovation (2011). Their framework began with teachers being exposed to an innovation that made them want to *focus* on the implementation of that innovation. Then, teachers want to explore the innovation; a stage they named *fiddle*. The final stage, *friends,* was confirming with colleagues and gaining additional knowledge from them. Frank et al.'s focus, fiddle, friends model was confirmed by their survey of elementary school teachers (2011). Again, these elements are similar to the DOI elements and the elements discussed in other diffusion theories.

DOI and Educational Research

There have been multiple studies within educational contexts that have used elements of the DOI framework. Pundak and Rozner use the DOI stages in an attempt to encourage college staff to adopt active learning (2008). Tabata and Johnsrud used an adapted version of the DOI characteristics which included the original five elements, but also adding *image*, *voluntariness*, and *result demonstrability* (2008); these three elements were added to account for overall social system characteristics that could affect adoption. Borrego, Froyd and Hall investigated the adoption status of RBIS in engineering departments across the country by surveying department heads and mapping with the DOI framework (2010). There have also been a number of explorations into the adoption of RBIS into engineering sciences courses (Borrego et al., 2011; Cutler et al., 2012; J. Froyd et al., 2012; Michael Prince et al., 2012).

Review of RBIS

Nine Research-Based Instructional Strategies (RBIS) were targeted within this study. These RBIS highlight a variety of the RBIS literature. They can be categorized into four groups, shown in Table 4.

Table 4: Overview of RBIS groups and descriptions of each RBIS

RBIS Groups	RBIS	Description of RBIS as presented in the interviews
Active Learning	Active Learning	A very general term describing anything course-related that all student s in a class session are called upon to do other than simply watching, listening, and taking notes
Group Learning RBIS	Collaborative Learning	Asking students to work together in small groups towards a common goal
	Cooperative Learning	A structured for of group work where students pursue common goals while being assessed alone
	Think-Pair-Share	Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions. After that, calling on students to share their responses
Self-Regulated Learning RBIS	Inquiry Learning	Introducing a lesson by presenting students with questions, problems or a set of observations and using this to drive the desired learning
	Just-in-Time Teaching	Asking students to individually complete homework assignments a few hours before class, reading through their answers before class and adjusting the lessons accordingly
	Problem-Based Learning (PBL)	Acting primarily as a facilitator and placing students in self-directed teams to solve open-ended problems that require significant learning of new course material
Real-Time Assessment RBIS	Concept Tests	Asking multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions
	Peer Instruction	A specific way of using Concept Tests in which the instructor poses the conceptual question in class and then shares the distribution of responses with the class (possibly using a classroom response system or “clickers”). Students form pairs, discuss their answers and vote again.

Active Learning

Active Learning is a generic term for any activity in the classroom that engages students in the learning process (Michael Prince, 2004). Due to the general nature of this RBIS, it includes each RBIS included in this study and could, therefore, be included in all of the following groups. As a result, Active Learning was given an independent group from the rest of the RBIS.

Active Learning is also probably one of the most studied RBIS with multiple studies looking into its effectiveness (Felder & Brent, 2009; J. E. Froyd, 2007; Michael Prince, 2004). An example of Active Learning is discussed by Barak who divided an introduction to programming course into three sections using web-based technology; one that was lecture based, one that incorporated partial active learning, and one with extensive active learning. It was found that the students in the partial active learning and extensive active learning sections better met the learning objectives than the lecture section (2007).

Group Learning

Group Learning (GL) RBIS require students to work together in the classroom. Three RBIS are included in this group: Think-Pair-Share, Cooperative Learning, and Collaborative Learning.

Collaborative Learning is a general term for any group work where students are working towards a shared goal (Barkley, Cross, & Major, 2005). These techniques can be formal group projects or informal classroom activities in which students work with a partner. Shooter and McNeal used Collaborative Learning in their interdisciplinary Mechatronics course to help students meet ABET criterion 3 learning objectives (2002).

Cooperative Learning, an RBIS that falls within Collaborative Learning, can be defined as a structured form of group work where students pursue common goals but are assessed individually (Millis & Cottell, 1998; Michael Prince, 2004). Hsiung divided a planar dynamics course into two sections: Cooperative Learning and individualistic learning (not working with a group). Over time, there was an increased performance with the cooperative learning group on both homework and tests (2012).

Think-Pair-Share is a quick strategy where the instructor poses a problem, has students work on it individually for a short time, has them form pairs and reconcile their solutions, and then calls on them to share their responses. (Felder & Brent, 2009) Byerley used multiple active learning techniques in a thermodynamics course, including Think-Pair-Share, and found an increase in students engagement and project performance (2001).

Self-Regulated Learning

Self-Regulated Learning (SRL) RBIS begin to transfer the responsibility for learning the content to the students. In this group, students are typically the ones that will seek out the content on their own and the instructor becomes more of a facilitator and resource for the students when they have trouble with the content. Two RBIS are included in this group: Inquiry Learning, Just-in-Time Teaching, and Problem Based Learning.

Inquiry Learning is an instructional strategy in which students are presented with questions to be answered, problems to be solved, or a set of observations to be explained (Kolb, 1984). Coller used Inquiry Learning in his Statics course and found that the electrical engineering students taking the course greatly benefited (as evidence by higher exam grades) when compared to another section that did not use Inquiry Learning (2008).

Just-in-Time Teaching (JiTT) calls for students to individually complete Web-based assignments a few hours before class; then the instructor reads through their answers before class and adjusts the lessons accordingly (i.e. “just in time”) (Michael Prince & Felder, 2006). Cashman and Eschenbach found that JiTT increased student engagement and confidence when implemented in their Introduction to Environmental Engineering course (2003).

Problem-Based Learning (PBL) centers on an open-ended, authentic problem that requires students to identify objectives and needs to find a solution for the problem. In this environment, the instructors take on the role of facilitator rather than source of information while students work in self-directed teams (Michael Prince & Felder, 2006). Reeves and Laffey used PBL in an Introduction to Engineering course and found an increase in the students' problem solving skills (1999).

Real-Time Assessment

Real-Time Assessment (RTA) RBIS are founded more on enabling the instructors to quickly assess student learning to address any common misconceptions or challenges the students are facing immediately. Three RBIS are included in this group: Concept Tests and Peer Instruction.

Concept Tests are multiple choice concept questions that use common student misconceptions as distracters (i.e. wrong answers) (Felder & Brent, 2009). These can be implemented in larger classes through the use of clickers, or similar voting methods, that require students to commit to an answer before discussing the correct answer. Santi used Concept Tests in a geological engineering course to address two common misconceptions (2007). He discussed the challenges to developing good conceptual question of equal levels of difficulty.

Peer Instruction allows students the opportunity to respond to a multiple-choice conceptual question (generally using some sort of classroom response system) and then discuss their response with a neighbor; this is then followed by a repeated response to the question (Pilzer, 2001). Koretsky and Brooks used Peer Instruction in a thermodynamics course for chemical engineering students and found that the quick feedback provided to faculty members greatly aided them in helping students address misconceptions. Also, on simple questions, they found an increase in student knowledge and understanding after completing the peer instruction exercise (2011).

Methods

Survey

The survey instrument used in this study was adapted from a previous survey of introductory physics instructors (Henderson & Dancy, 2009; Henderson, Dancy, & Niewiadomska-Bugaj, in press) and a separate survey of Electrical, Computer, and Chemical Engineering instructors for engineering sciences courses (J. Froyd et al., 2012; Michael Prince et al., 2012). The Statics instrument was divided into five sections (as seen in Appendix A). The first section asked when the instructor had most recently taught Statics. The second section asked the instructor about his or her teaching and learning beliefs. The third section asked the instructor to estimate the amount of class-time spent on different listed activities. The fourth asked the instructor about his or her level of knowledge and use of the nine RBIS specific. The fifth section included demographic information such as gender, rank, and frequency of attendance at teaching workshops and is not listed in Appendix A. This study focuses on the fourth section, where instructors were asked about their familiarity with the different RBIS. For the findings from section three, refer to (Manuscript 1).

Survey Data Collection

Statics instructors were identified by compiling a list of all accredited US mechanical engineering programs (n = 285) as well as 7 civil engineering and 4 aeronautical/aerospace engineering programs at institutions that do not offer mechanical engineering. The Virginia Tech

Center for Survey Research (CSR) staff contacted each department via telephone with email follow-up to identify the Statics instructors. The protocol included identifying which department was responsible for the course and following up as appropriate.

Each instructor was invited to complete the survey via a personalized e-mail signed by Paul Steif and Anna Dollár, established Statics professors and researchers. The survey was administered in spring 2012. The survey was administered in fall 2012 to 764 faculty.

Responses were screened to ensure respondents had taught Statics within the last five years and had completed a majority of the survey items. Any participant who did not meet these characteristics was removed from the analysis. Out of the 205 initial responses, 166 Statics were usable.

The Statics survey was sent to 764 instructors with 166 responses and a response rate of 22%. Of the 166 usable responses, 20% of respondents were female and 62% male (18% did not respond); 13% were lecturers (i.e., not tenure track), 17% assistant professors, 25% associate professors, 17% full professors, and 10% listed their position as other (18% did not respond). The respondents came from a variety of engineering departments or programs: 34% mechanical engineering, 34% civil, 5% aerospace/aeronautical, 2% engineering mechanics, and 7% indicated “other” (18% did not respond).

Survey Data Analysis

Each RBIS was combined into four different RBIS groups: Active Learning, Group Learning, Self-Regulated Learning, and Real-Time Assessment (Table 4).

For each RBIS, the survey responses were totaled by response options (shown in Table 5).

Table 5: Levels of Familiarity from Survey Response Options

Level of Familiarity	Survey Responses
Currently Using	I currently use it
Has Tried, but not currently using	I have used it in the past
	I have used something like it but did not know name
Knows about, but hasn't tried	I am familiar with it, but have never used it
No Knowledge of RBIS	I have heard name, but know little else about it
	I have never heard of it

Interviews

The qualitative component of the current study included faculty interviews at universities in the state of Virginia. I conducted and recorded the interviews in-person at each university. Each interview lasted between 35 minutes and 2 hours, with the average being approximately 1 hour. I then thematically coded the interviews after they were transcribed using a transcription service.

Interview Protocol

As shown in Appendix B, the interview protocol addressed various areas of interest. Each instructor was asked about typical activities that the students completed in their Statics classroom and the influences on those decisions (which is discussed in Manuscript 1). Instructors were also asked if and how they used a list of RBIS in the Statics classroom, how they began using RBIS, and any changes they made when implementing an RBIS.

Interview participants were also asked to complete a "table activity" (seen at the end of the interview protocol in Appendix B) where they examined each RBIS with respect to the five characteristics (Relative Advantage, Compatibility, Complexity, Trialability, and Observability) that DOI identifies as influences on adopting an innovation. The interview participants were asked to mark each characteristic as a benefit (i.e. positive influence on adoption), a barrier (i.e. negative influence on adoption), or a non-influence on adoption for each RBIS. In addition, the participants were asked to talk-aloud while completing this activity verbally discussing the reasoning behind their decisions. This activity is referred to as the *table activity*.

Interview Participants

Participants were chosen through purposeful sampling (Creswell, 2009) of faculty members teaching Statics courses at universities in the state of Virginia with ABET Accreditation; list provided in Table 6. The selection began by identifying universities with ABET accredited engineering programs in the state of Virginia. I then used university websites and course catalogs to identify which universities offered Statics and in which department. Each department was then contacted to obtain the name of the faculty member who had most recently taught the course. For many departments this was the same list of faculty who were contacted to participate in the survey. Each instructor was then sent an e-mail invitation to participate in the study. After two weeks, a reminder e-mail was sent and the instructor was contacted by telephone. At least one interview was conducted at each of the identified universities in Table 6.

Table 6: VA ABET Accredited Schools offering Statics

University	Course Number	Course Title
George Mason University	ENGR 210	Statics and Dynamics
Hampton University	ARC 309	Structures (Architecture)
James Madison University	ENGR 212	Statics and Dynamics
Old Dominion University	CEE 204	Statics
Sweet Briar College	ENGR 205	Statics and Strength of Materials
University of Virginia	MAE 2300	Statics
	CE 2300	Statics
Virginia Commonwealth University	ENGR 102	Engineering Statics
Virginia Tech	ESM 2104	Statics
	ESM 2214	Statics and Mechanics of Materials
Virginia State University	ENGR 210	Statics/Strength of Materials
Virginia Military Institute	ME 201	Statics
J. Sergeant Reynolds Community College	EGR 140	Engineering Mechanics - Statics

Virginia was selected for a number of reasons. First of all, there is a diversity of institutions offered within the state, listed in Table 6. There are public and private institutions as well as an all-women college, a military institute, and two Historically Black Colleges and Universities (HBCUs). There are large and small universities with large/small, old/new engineering programs in varied locations such as in a city or on a land grant. In addition, there is also a number of community colleges that offer Statics. The second reason was resources. To suitably complete this study, in-person interviews were necessary for the completion of the table activity within the interview. This element was more complex than answering questions and, in-person, the interviewer was able to see what the participants were doing, which enhanced the interview data by allowing for additional probing questions to clarify answers. To complete in-person interviews, I traveled to the institutions. Driving through Virginia required less time and financial resources than would have been necessary to fly around the country. However, by limiting the scope of the study to schools in Virginia to save resources, the diversity and richness of the data was not limited (except geographically).

An overview of participant characteristics can be seen in Table7. From the interviewer's observation (not reported by participants), the instructors interviewed include one female, one person of Hispanic/Latino ethnicity, and one of African descent. All others were males of European/Caucasian or Asian descent (e.g., from India or China). Due to the singular nature of having one female participant, each paragraph of the results section will alternate male/female pronouns to protect her identity.

In Table7, the universities were characterized according to the Carnegie classification. An asterisk was added to universities that had a specialized focus such as Historically Black Colleges and Universities (HBCUs), women's colleges, and military institutes. The instructor's letter designation from Table7 will be indicated following each direct quote in the results section to add some context to the quotes that are given.

Table 7: Characteristics of Interview Participants

Instructor	Years Teaching Statics	Total Years Teaching	Rank	Class Size	Instructor Degree	Carnegie Classification
A.	> 20	> 20	Prof	> 100	Mech Engr	Very High Research Public
B.	> 20	> 20	Prof	> 100	Mat Sci	Very High Research Public
C.	> 20	> 20	Prof	21 - 40	Mech Engr	Non-PhD granting Public*
D.	> 20	> 20	Prof	Unknown	Civil Engr	High Research Public
E.	> 20	> 20	Associate Prof	>100	Engr Sci Mech	Very High Research Public
F.	> 20	> 20	Associate Prof	>100	Physics	Very High Research Public
G.	6 - 10	11 - 20	Associate Prof	> 100	Mech Engr	Public State
H.	6 - 10	11 - 20	Associate Prof	> 100	Mech Engr	Very High Research Public
J.	6 - 10	11 - 20	Associate Prof	21 - 40	Mech Engr	Non-PhD granting Public
K.	≤ 5	11 - 20	Prof	≤ 10	Elec Engr	Non-PhD granting Public*
L.	≤ 5	11 - 20	Adjunct	21 - 40	Chem Engr	Community College
M.	≤ 5	≤ 10	Prof	≤ 10	Physics	Non-PhD granting Private*
N.	≤ 5	≤ 10	Associate Prof	≤ 10	Mech Engr	Non-PhD granting Private*
O.	≤ 5	≤ 10	Assistant Prof	21 - 40	Mech Engr	High Research Public
P.	≤ 5	≤ 10	Assistant Prof	21 - 40	Civil Engr	High Research Public
Q.	≤ 5	≤ 10	Adjunct	21 - 40	Civil Engr	High Research Public
R.	≤ 5	≤ 10	Adjunct	21 - 40	Mech Engr	Community College
S.	Unknown	Unknown	Adjunct	21 - 40	Architecture	Non-PhD granting Private*

* Indicates that university has a specialization including: women's colleges, Historically Black Colleges and Universities (HBCU), and military institutes

Interview Analysis

The qualitative analysis began with *a priori* (Tashakkori & Teddlie, 2003) coding for the 5 characteristics of DOI as directly referenced by the participants during the table activity. Every time a participant referenced the Relative Advantage, Compatibility, Complexity, Trialability, or Observability of the different RBIS, it was coded with the appropriate characteristic. One of the goals of this study was to gain the instructors' perspectives on these characteristics and how these apply to each RBIS; therefore, only comments specifically addressing the characteristics discussed during or after the activity were included in these codes. The relationships between RBIS and DOI characteristics presented here are those discussed by the interview participants, not those of the author and may not align with the reader's views on these relationships. The relationship between the instructors' comments and the literature will be presented in the Discussion section.

A second round of interview coding used open coding (Strauss & Corbin, 2008). In general, when using open coding, the interview transcripts are coded for initial concepts and deeper meanings. Initial concepts are then abstracted into codes that join similar concepts together through the constant comparative methods (Glaser, 1965). As more codes are added and constantly compared, the nature of the categories may evolve or expand to appropriately address the ideas present. For the open coding of these interviews, fifteen general themes initially emerged; the implementation influences will be the focus of this study. Six codes were categorized within the implementation influences theme: class size, inertia/instructor characteristics, time, university support, outside resources, and student characteristics. The interview participants expressed class size and time collectively when they discussed the DOI characteristics and, therefore, will not be discussed separately in the results. University support and inertia/instructor characteristics were distinctly discussed by a majority of the instructors and will be discussed more thoroughly in the results section. Outside resources and student characteristics are not discussed here as only one or two participants discussed them and they were not discussed in a way that added substantial insight to this study.

Results

The results section begins by discussing the quantitative results from the survey to establish a baseline measure of the level that Statics instructors have adopted these RBIS nationally. Next, the DOI characteristics will be discussed; here I am highlighting common barriers that were identified for each DOI characteristic by the interview participants. The Relative Advantage was discussed with respect to each RBIS group, discussing the advantages and disadvantages of each group. Compatibility was discussed in a more general tone with many instructors indicating that all of the RBIS, or all but one group, were compatible with their individual view on how learning occurs. Complexity was most commonly cited as a barrier, with time and class size being discussed universally across all RBIS groups. Characteristics of individual RBIS groups were also discussed as barriers to adoption. Trialability echoed the time, class size, and RBIS group characteristic concerns of Complexity. Observability was most generally discussed with the barriers identified as a lack of data, lack of knowledge of evaluation methods, and a non-uniform objective for using RBIS. Finally, the emergent codes are discussed. An overview of the results can be seen in Figure 1.

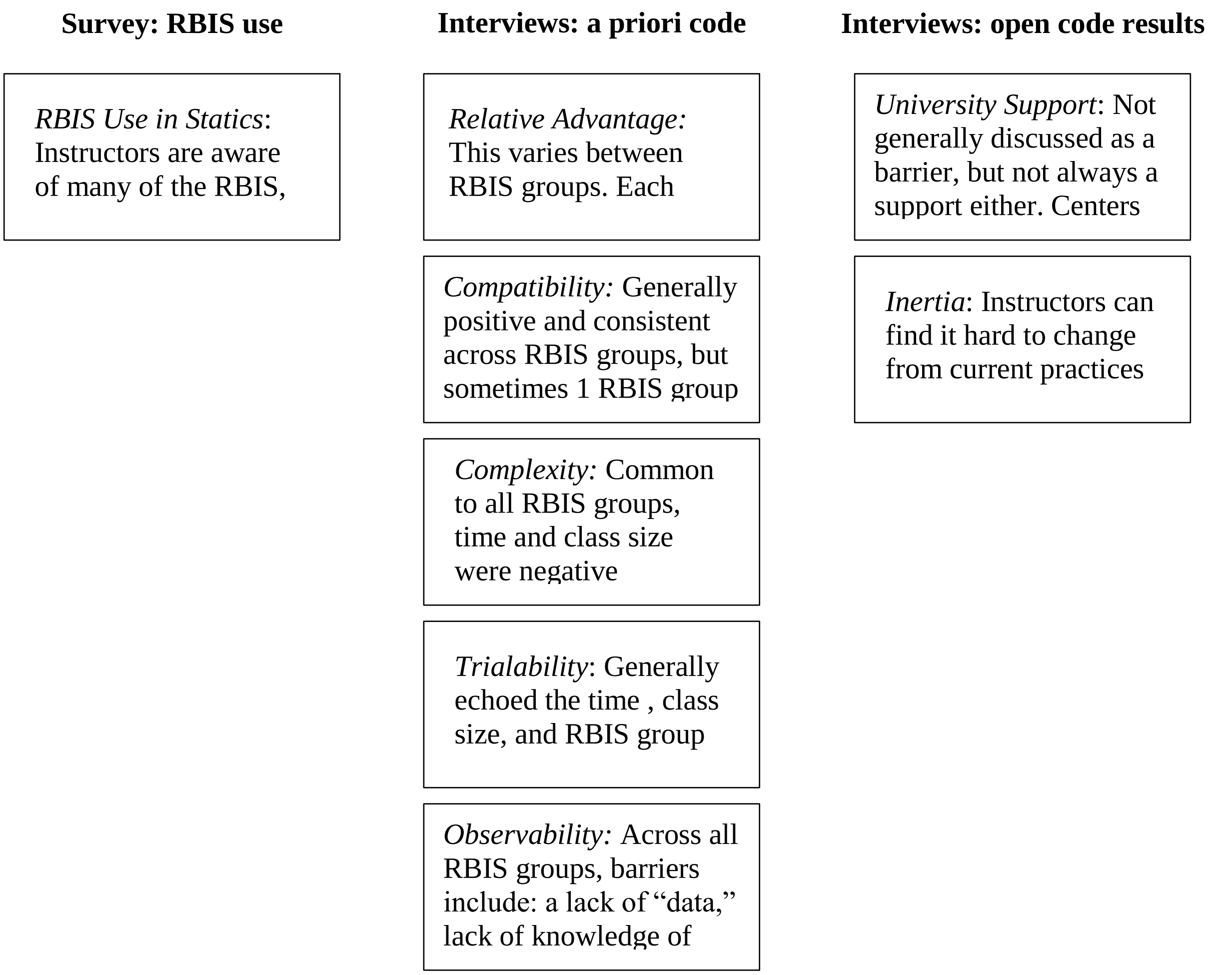

Figure 1: Overview of Results

RBIS use in Statics

Through the collected survey data, each RBIS group was examined for the level of familiarity of the respondents. This aided in establishing a baseline of dissemination for each RBIS group, which can help inform the barriers faculty members are currently facing. The average response for each group is presented in Figure 2.

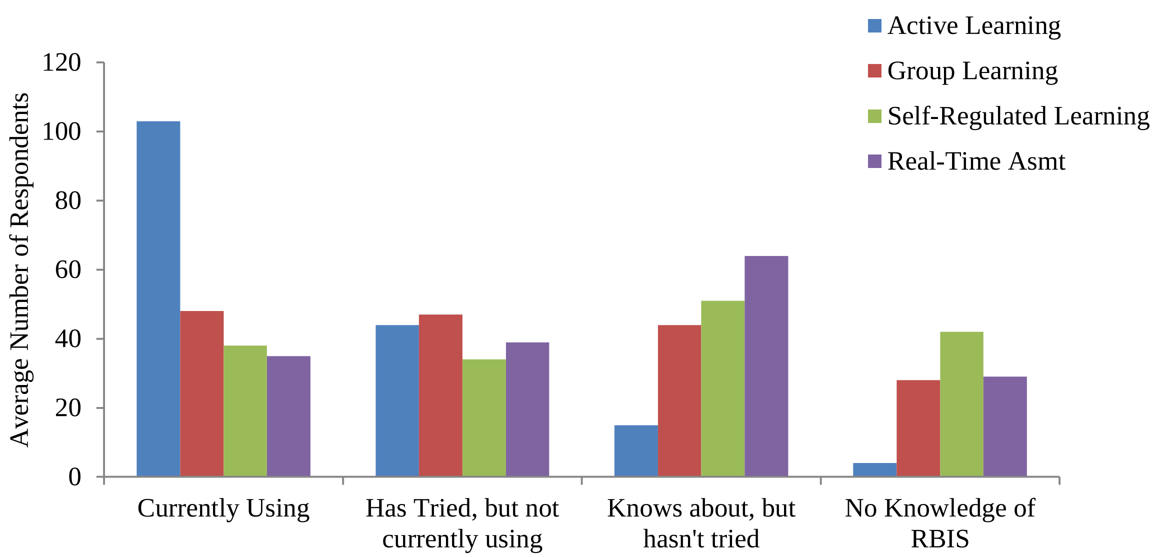

Figure 2: Survey Respondent familiarity with RBIS Groups

As shown in Figure 2, Active Learning is the most used RBIS group with the fewest respondents having no knowledge of it. This is not surprising due to the general nature of Active Learning. The other RBIS groups showed varying trends. Group Learning RBIS (Collaborative Learning, Cooperative Learning, and Think-Pair-Share) had fairly even averages across each level of familiarity with the lowest percentage having no knowledge. Self-Regulated Learning RBIS (Inquiry Learning, Just-in-Time Teaching, and Problem-Based Learning) were also fairly consistent across the levels of familiarity; however, the averages increase as the familiarity with Self-Regulated Learning RBIS decreases ending with the highest average of respondents having no knowledge. The smallest number of respondents indicated currently using the Real-Time Assessment RBIS (Concept Maps and Peer Instructions); there were also a higher number of respondents who indicated they knew about Real-Time Assessment RBIS, but had not tried them in the classroom.

For the overall familiarity of survey respondents with the RBIS groups, the smallest averages reflected the lowest level of familiarity, no knowledge of RBIS. This similar results as to those found in the literature that many of the instructors are aware of RBIS but then either do not try them or try them and then stop using them (Cutler et al., 2012; Henderson et al., submitted 2012). The reasons why instructors do not use these RBIS or discontinue their use are investigated through the interview responses in the following sections.

Barriers to RBIS Implementation

Relative Advantage

Most of the instructors felt that there was a Relative Advantage to using most, if not all, of RBIS over a traditional lecture. One instructor discussed the influence of the Relative Advantage on his decisions to adopt a new teaching strategy saying, he would overcome the other negative aspects of the other characteristics "but if I don't find a Relative Advantage of it" (F.), he wouldn't use it. This instructor feels that the other DOI characteristics are not as important to adopting as finding the Relative Advantage of an RBIS. Many of the instructors indicated that they did see a Relative Advantage with the RBIS presented. Instructors commented saying things like, "Lecturing, they're not engaged. They're not engaged in it. And part of learning is you've got to own it" (E. Think-Pair-Share) and "Anytime where you got kids with their mouths open, I think that's, I think learning is happening" (O. Cooperative Learning). One instructor stated, "Hopefully, it motivates them to sort of get their mind into the material and think about it in the context of some of the stuff they may be using it for" (B. Inquiry Learning), and "I think that students doing things is almost always better than me telling them how they might do it later" (M. Think-Pair-Share).

Relative Advantage of Active Learning

The Relative Advantage of Active Learning was not identified as a barrier to using Active Learning by any of the interview participants. All of the interview participants felt they were using some element of active learning in their class and that it was a positive element to the class. Some of the comments made about the advantages to using Active Learning in the classroom were: “[The students] need to know what’s going on actually. If they don’t know what’s going on, they’re going to be lost” (R. Active Learning), “I see a significant advantage to that because it’s less dull, I guess, in my opinion, and probably because it has something to go with my Compatibility. I think that I learn by doing instead of watching, and that’s I guess that’s it. That’s why it’s an advantage to me” (J. Active Learning), and “I think anything that helps the students do something other than watch is good” (B. Active Learning). Instructors highlighted that Active Learning can help to engage students during a traditional lecture as well as getting them to participate in their learning, which was an advantage over a traditional lecture.

Relative Advantage of Group Learning RBIS

The Group Learning RBIS group was one of the dividing groups of RBIS amongst the instructors. A number of instructors were very enthusiastic about the benefits to using RBIS making comments such as, “Students are thinking together, working together, sharing concepts, and how they view the materials is a great thing” (J. Collaborative Learning) and “I see the advantage to it because, once you graduate, you’re going to be working in a team. You’re never going to be out there by yourself” (S. Think-Pair-Share). Each of these instructors referenced the importance of bringing teamwork and collaborative skills into the classroom and felt there would be a large advantage to using RBIS to do this.

However, another subset of instructors were worried that having students work in groups or teams encouraged "peer *leaning*" and that there was a challenge to ensure that all of the students, as opposed to a few, learned the material. One instructor explained that she felt, "You put students in a group of three or four… and one person will always dominate the lead, and that's the lead, and that's the person who learns, and the others just follow, and they don't learn very much" (E. Cooperative Learning).

Relative Advantage of Self-Regulated Learning RBIS

The Self-Regulated Learning RBIS were highlighted for their advantages over lecture because they made students responsible for their own learning and they allowed connections to be made between the classroom and the application of Statics principles. One instructor stated that by using an RBIS she "Let [the students] know the connection between the Statics course and something either in real life or something related to the subsequent courses" (D. Inquiry Learning). Another instructor discussed the importance of transferring the responsibility of learning from the instructor to the students saying:

> It makes [the students] responsible for their initial contact with information, so that I'm not telling them information that is obvious, and … they could get easily for me, but it's in the book, too, as opposed to the things that are challenging that the book may or may not do a great job with. And I think that's important, facing information on your own is an important part of learning. An then deciding what you know or you don't know based on that, and that all being kind of okay, and coming to class going, paragraph 3 page 50, I don't, what are, I don't know what that means, is a great way for class to start. (M. Just-in-Time Teaching)

This instructor felt that having students figure out some of the information on their own helped students to better learn the material. Another instructor expressed a similar sentiment saying, "We prepare the students to learn something [where] he uses [his] brain, his effort to solve that kind of problem to do [it] on his own, so he is ready to get the teaching things" (K. Just-in-Time Teaching).

However, where a number of instructors found the benefits to using the Self-Regulated Learning RBIS, some found that they were not appropriate for the Statics Classroom. The Relative Advantage to using Problem-Based Learning (PBL) was marked as a barrier more than any other RBIS. One instructor commented that "Statics is one of those classes where you say, 'Okay, you are given a truss and how much force does this truss carry?' So it's just more a direct problem" (P. Problem-Based Learning). This instructor, like others, felt that the materials in Statics did not lend themselves to PBL, thus decreasing the advantage to using PBL. Though instructors did not necessarily feel it was appropriate in Statics, they did see the advantage to using PBL in more advanced courses.

Relative Advantage of Real-Time Assessment RBIS

The Real-Time Assessment RBIS were another group where the responses of the interview participants diverged. Multiple instructors thought the real-time component was a benefit that helped give students quick feedback. One instructor stated, "You are responding, when you teach, you've got to respond to what the students are understanding, and so it's a matter of capturing what the students are understanding and adjusting your lecture to, to talk about those kind of things" (F. Concept Tests and Peer Instruction). This instructor discussed the importance of, as an instructor, being able to constantly know how well the students understand the material, and RBIS can help the instructor do that. Another instructor echoed this when probed for why Concept Tests had a check for Relative Advantage, “A huge advantage…It’s checking, it’s you know, basic learning. How are we doing? How am I doing? Are we getting to the point?” (L. Concept Tests). Again, RBIS offer instructors a way to assess how well the students understand the material and adjust their lectures to address concerns.

However, there were a few instructors that were not fully convinced that the advantage of the Real-Time Assessment RBIS was greater than that of lecturing. One instructor expressed his concerns saying, “I’m not nuts about it…for me, it kind of smacks of tricking students into the wrong answer, and once they’ve gone down the wrong path, backing them up to the right path can be difficult to do” (N. Concept Tests). Another instructor stated, “[Concept Tests have] an advantage because the students will understand the concept more versus just crunching the numbers, but I don’t think it can override the traditional lecturing, so I’m halfway on this” (P. Concept Tests). Many instructors thought there was a positive benefit to using the Real-Time Assessment RBIS, but some of them expressed some concerns that would be a barrier to using RBIS.

Compatibility

Overall, the majority of instructors found most, if not all, of the RBIS consistent with how they think learning occurs. Interview participants discussed the Compatibility of different RBIS saying things like,

> It is very compatible with the way I think… particularly making observations, and then how do those observations correlate with each other. That's a critical skill for science and engineering, and I think the more they have practice at it, the better. And if we can give them the practice while they're learning material that's important (J. Inquiry Learning)

and

> When you're learning you're making, making an assumption of how something works and then working a problem and testing that assumption whereas if this is a very up-front method of okay, here's some ways where it's implemented wrong and right, the question then becomes well, why are they wrong or right (Q. Concept Tests).

For a number of instructors, many of the RBIS were compatible with how they think learning happens, but there was one specific RBIS (or RBIS group) that was not completely compatible. One instructor stated,

> I'm a big believer in the social element of learning, and a lot of these [RBIS] have that element to it. Concept Tests probably not so much…that strikes me as less of a pedagogical device than an evaluation thing…And really, the rest of these all seem compatible with the way I think about learning, for sure….You're [the instructor] responsive, you're giving students feedback, you're addressing their concerns, you're making sure that they understand that you hear them, and you are understanding what challenges they face. So, that all seems okay. (G. All RBIS)

This instructor believed that all of the RBIS could help students learn, but in different ways. Many of the RBIS are fueled by interactions, but Real-Time Assessment RBIS (more specifically, Concept Tests) are different and need to be used in a different way. The Real-Time Assessment RBIS Tests were pointed out by a number of interview participants as not completely compatible with how they think learning occurs. Another instructor stated,

> I'm not sold; I'm not saying that they're not good. I'm just saying it's obvious to me that you can just take the flat answers and move forward. I think that if students are coached on how to deal with concept-based questions rather than just having them dropped on them, that can make a difference. So I think there's a, as with any testing, I think there's a lot of variability there" (O. Concept Tests)

This instructor expresses her concern for using Real-Time Assessment RBIS because she thought some students would just learn how to manipulate the assessment, hear multiple-choice questions, and not learn the underlying concepts.

Another set of faculty members reiterated their concerns about Group Learning RBIS. As with the Relative Advantage of many RBIS, instructors generally discussed being torn about the benefits and challenges of the Group Learning RBIS. One instructor discussed this saying, "It seems to me there's learning from the person who doesn't quite understand is occurring in a different way than for the person that does understand, and both of those can happen in this, but the other one’s saying similar to how you think learning occurs, so I don’t know, maybe that is yes” (B. Cooperative Learning). A number of instructors expressed this concern along with reiterating their concerns about social loafing and the challenge of ensuring each individual student learns the material.

It is evident from these comments and others that instructors have a variety of views on teaching and learning; this became apparent through discussing the perceived benefits and barriers to the different RBIS groups. Many instructors were supportive of the Group Learning RBIS but concerned about the learning that happens with Real-Time Assessment RBIS or vice versa.

Complexity

Complexity was reported as the most common barrier to instructors using different RBIS. One instructor discussed the overall influence of Complexity saying, “The daunting-ness of thinking, ‘Oh, gosh, I need to make up all these examples and put them down on paper in some type of worksheet form,’ I don’t have time to do that, I really think that is probably the primary…So if it’s going to require a significant amount of time to develop it, I don’t think it’s going to be widely used” (J.). As discussed in this quote and highlight by a number of other instructors, one of the primary concerns with the Complexity of an RBIS was time: the time it takes to plan the implementation and the actual time it requires in the classroom. Again, these are the perspectives of the instructors to the meanings of the characteristics and their view of what makes an RBIS complicated to implement. These will be explored in the next section; followed by class size which was also discussed independently of a specific RBIS group. The final element of Complexity discussed was specific to the characteristics of each RBIS group.

Time as a Complexity Barrier

Preparation time, as well as time away from content coverage, was cited as a common challenge for most RBIS across groups. One instructor commented, "I think converting a lecture-based sort of, of, approach to doing a course to an active one, I think would be a challenge as far as starting a course from zero and incorporating active elements, I think that's less of a challenge" (O. Active Learning). This instructor comments that he thinks Active Learning is more complex, i.e. takes more time, when the instructor is trying to incorporate it into an already existing course as opposed to using it in a new course. One instructor commented, "How hard will it be to use it? That would take a lot of time" (K. Think-Pair-Share). Another instructor also referenced time as a barrier saying, "[Group classroom mini projects] usually require a pretty big chunk of time to implement. If the students are doing that, they're not doing, you know, drill homework problems, right, and I think that's a trade worth making, but it comes at a cost, right?...it usually takes a fair amount of planning to do it right" (N. Cooperative Learning and Collaborative Learning). Preparation time was also discussed by a number of instructors making comments such as, "It just seems to me that you've got to put a lot more thought into creating that experience, and there's a lot more time involved obviously" (G. Inquiry Learning).

Class Size as Complexity Barrier

As an element of Complexity, class size was consistently, across all RBIS groups, referred to as a barrier to RBIS use. Instructors referenced this with Group Learning RBIS by saying:

> "I would see a big challenge here. If you have a big class, how do you accomplish this and then also, in a timely manner, cover the content that you are trying to cover? So Statics may not be a good class for this kind of approach" (P. Think-Pair-Share),

> "I got to have a structured form, I have to have an organized form. Plus, it means additional feedback to the students, which is, means a little more attention has to be paid. So depending on how big the class is, you know, if I double the size of a class, I'd probably quadruple the work"(L. Cooperative Learning & Collaborative Learning),

> and "Again, this Think-Pair-Share with my smaller class would, yeah, we've got time to do that. With the larger class, it's not going to work" (A. Think-Pair-Share).

The emphasis on class size also echoes the Complexity barrier of taking extra time to implement RBIS in the classroom.

An interesting element that is typically not discussed in the RBIS literature is that the Complexity barrier of class size applies to small classrooms as well as large classrooms. One instructor, who had less than 10 students in his class, commented that, "We can get input from the students themselves, then we can change what we did wrong" (K.). When discussing the Complexity of an RBIS, she went on to say, "For small size, it doesn't work. For large class, it's so hard organizing" (K. Peer Instruction). The Complexity barrier can reflect challenges implementing RBIS in a small or large class.

RBIS Group Characteristics as Complexity Barrier

Complexity was also discussed by the instructors in terms of each RBIS group and the specific characteristics of them that created more barriers for them to implement. Each of the groups will now be discussed.

Each of the Group Learning RBIS had a nearly even number of participants discuss Complexity as a barrier and as a benefit. The elements highlighted by previous discussion as a benefit of the Group Learning RBIS are now presented as a barrier for implementation. One instructor commented, “Teamworking, it has its own Complexity, not only in Statics, in any other things. And that Complexity, some students, it depends on their character and how to select the students and put into one team” (K. Cooperative Learning). Creating and facilitating teams can present an additional level of Complexity that inhibits some faculty members from wanting to use the Group Learning RBIS in their classroom.

Self-Regulated Learning RBIS were marked as barriers with respect to Complexity due to the - open-ended nature of the RBIS. One instructor thought the Complexity of the Self-Regulated Learning RBIS resulted from the fact that they required open-ended problems and that open-ended problems were not part of Statics. He explained saying:

> [Statics] is a very analysis-oriented course…You’re not necessarily taking a higher-level skill like synthesis of, you know, what do I know about what are appropriate assumptions to make or not to make, or what information is valuable or not valuable or whatever. You know, you’re not engaging that higher-level thought process. Whereas with the inquiry-based, I think you are, and I think that makes it a little bit harder to implement. (G. Inquiry Learning)

This mismatch of course content level and the level required to use these RBIS created a Complexity for implementation that inhibits the instructor from wanting to adopt these RBIS. Another instructor explained the Complexity of actually implementing a Self-Regulated Learning RBIS saying,

> In some classes I've run projects like that where it's very open-ended, and it's difficult. It's not as predictable to guide the students through. Ultimately, I think they have a great learning experience, but it may not always end up being the learning experience that I thought that they would have, okay, so it's complex to make that happen" (J. Problem-Based Learning)

These RBIS that require students to take responsibility for their learning can become unpredictable and challenging for the instructor. In a fundamental course like Statics, this barrier can be enhanced due to strict content that needs to be covered.

For Real-Time Assessment RBIS, a number of instructors discussed the implementation challenge of needing to use associated technology, primarily when referring to the use of clickers for Peer Instruction. One instructor said, "So if you thought it would be kind of really complicated to maintain it or, like you were talking about with the clickers, it's really complicated to kind of set that up" (H. Peer Instruction). While another echoed this sentiment saying, "The reason I didn't [use clickers], I went over to the bookstore, and the bookstore is selling six different types of clickers, and they expect the students to all buy, you know, one. If our university would say, this is the standard, one clicker is going to work in all the classrooms, I would probably adopt that" (A. Peer Instruction). The technology requirements for implementing the Real-Time Assessment RBIS increase the Complexity of implementation causing it to be reflected as a barrier to implementation.

Trialability

Trialability responses highly echoed the responses for Complexity. However, one of the most salient difference between Complexity and Trialability is that for some of the RBIS believed to be more complex, the instructors thought that trying it once would not be as much of a barrier. When beginning her evaluation of the Trialability of the different RBIS, one instructor stated, "I think they're going to mimic this Complexity thing, in many respects" (B.). She went on to explain her reasoning saying, "I think the reasons I wouldn't use it on the routine basis is the same reason I would find it difficult to do it one time" (B.). As implied by this instructor's explanation, overall, many of the concerns that were expressed when discussing Complexity were echoed when discussing Trialability.

As with Complexity, the amount of class time required to implement various RBIS was a barrier for trying and adopting. One instructor stated, "[Trying it is] not that difficult…I think that that's possible. The only thing is, you know, how much time I could afford it during the class" (D. Think-Pair-Share). Again, the instructor emphasizes that finding time in class to use RBIS is a critical consideration for whether or not to implement it. Another instructor expressed concerns about spending the time upfront to create the materials for an RBIS saying, "I think it requires a little more forethought, a little more time up-front invested, so I think, you know, I don't think it's impossible, but I think it's a, more time investment up-front" (G. Collaborative Learning and Cooperative Learning). If an instructor is only going to *try* an RBIS as a onetime implementation, it can be hard to justify the time required upfront to coordinate some of the more involved RBIS.

The Group Learning RBIS were specifically discussed as a challenge to Trialability. Again, time played a key role in the discussion, but a number of instructors specifically discussed a challenge in relation to the time it takes to coordinate and implement the Group Learning RBIS. One instructor stated, “It’s a challenge because, once again, group work lags the class” (R. Collaborative Learning). Another stated, “it usually takes a fair amount of planning to do it right. Trying it, trying it first isn’t so easy” (N. Cooperative Learning). Where time was discussed as a challenge for Trialability with all RBIS, the Group Learning RBIS were specific targeted as more time intensive to try.

The Real-Time Assessment RBIS were again targeted for the technology that is required for implementation. Specifically the technology and support required using “clickers.” One instructor stated, “It’s hard to introduce the new technology. It requires institutional support, and it requires the learning curve for me to come up to speed” (C. Peer Instruction). Another commented, “If you had clickers, then there’s a lot of like hardware and stuff that you have to get to help set that up, so that’s kind of hard to try” (K. Peer Instruction). Having technology components that are not already being used for the class, add an additional barrier to implementation by limiting the instructors’ ability to try the implementation.

Observability

Observability was marked as a barrier to adoption second only to Complexity and most obviously transcended the RBIS groups. Very few comments that were made by the interview participants were specific to one RBIS group. More than one instructor marked Observability as a barrier for all of the RBIS without discussion about the individual characteristics of the RBIS. The common ways in which the instructors discussed Observability as a barrier will be discussed in the following subsections.

Lack of "Data" as Observability Barrier

A number of instructors cited a lack of "data" to determine if an RBIS is working as a barrier. One instructor said, "Everything a [benefit] except for how well it's working [i.e. Observability]. I don't have data. I haven't done it" (D. Inquiry Learning). Another instructor also discussed his hesitation with the Observability of an RBIS saying, "I don't know, all of this Observability, I don't really know how you would get data out that would tell you whether it's working or not, so I don't really know about that" (F. Concept Tests). Another instructor was also challenged by the idea of Observability. It was not necessarily a lack of data, but a lack of trust in the data. She said, "I tend to think of [Observability] as not a simple thing, and not because I can't, say, give them a test and look at the numbers that come back, but it's not obvious to me that the numbers aren't lying or at least maybe fibbing a little bit" (O. Concept Tests). Another instructor notes the anecdotal nature of the "data" she uses to evaluate the Observability saying, "When it comes to Observability, I think, general feedback I get is it works, but I haven't measured it" (P.). One instructor referenced her small class size as a challenge for collecting enough data for any of the RBIS to be observable saying, "Nothing is observable here. When you only have that few [students]…I mean you just don't have enough students" (N.). The instructors expressed that the lack of proven data was a barrier to the Observability and, therefore, the implementation of RBIS. The focus on data may reflect the engineering mindset that heavily relies on quantitative, empirically derived solutions to inform practice and design decisions.

Lack of Methods Knowledge as Observability Barrier

Multiple instructors said that the barrier to Observability was that they were unfamiliar with the methods needed to know if an RBIS worked. One instructor expressed a concern for not having formal techniques in place to measure the benefits of RBIS. He said:

> You could make offhand comments like ‘hey, students are talking about Statics to each other, and that’s a good thing.’ And so maybe that’s an observation that you could make, but at the end of the day being able to say whether students are better able to analyze a truss with one approach or the other, I think you have to actually come up with a good way of testing that….[W]e’ve looked at different ways of tests and stuff, and I’m not, even with a standardized test there’s variability. There’s semester-to-semester variability and the students themselves and that sort of thing, so I think any observations… challenges. (O. Active Learning)

This instructor discussed the challenge of evaluating RBIS in the classroom because he was not sure exactly how to assess the use of RBIS. Other instructors express a general lack of confidence, or knowledge, when evaluating RBIS; some examples of their comments include: “How well to see if it works. That that was working better than something else…I don’t know. I mean, I’m going to give it a zero because I’m not sure… I mean, I don’t think with me it’s necessarily going to be any more obvious than anything else” (Q. Think-Pair-Share), “I don’t know how to assess it” (F. Cooperative Learning), and “I have to ask them in a group, and I did ask them some questions at the end of one of the exams. Did you learn anything from this? Some did. Some didn’t….So I kind of want to be, to be able to do this assessing alone…I don’t know how” (H. Collaborative Learning).

Unknown RBIS Objective as Observability Barrier

When discussing Observability as “how easy is it to see if an RBIS is working?”, there was not a consensus of how instructors defined “working.” When first considering Observability, one instructor stated, “The question then becomes ‘how, what is the method by which you evaluate any of these?’” (Q. Active Learning). When prompted to think about how she knew the active learning she used was working, she said, “If they’re not distracted, then it seems like, you know, they seem to be understanding the concepts on an evaluation, that seems to me would be the way to judge. I’m not sure what other metrics would be to judge” (Q. Active Learning). Another instructor specifically targeted this issue while talking through the Observability for a specific RBIS,

> Observability, again, I’m going to say that it depends on what you’re after… I think with Problem-Based Learning teaching specific content is not, because of the unpredictability of it is not necessarily going to happen…you may or may not get there with an open-ended problem, but the other maybe non-tangibles, such as teamwork, cooperation, learning independently, that builds, so I think you can observe those aspects, the personal development of the student, but I think it’s difficult to observe specific learning objectives with regard to specific learning content. (J. Problem-Based Learning)

This instructor is challenged by determining the benefits and success of implementation of this RBIS because there are some objectives that will be met more easily than others with the use of the RBIS. The variations in how instructors discussed and evaluated the Observability also reflected the different measures each instructor had for what it meant for an RBIS to be working. As discussed in the previous subsection, a number of instructors were looking for proof that

RBIS are significantly different than one another or lecturing; some faculty members discussed using the feeling of engagement within the class as an observable way to judge that an RBIS is working. This showcases that the instructors had different definitions for what it meant for RBIS to be "working:" some thought this meant student engagement where others where others were looking for improved student understanding. Surprisingly, more instructors were confident of assessment of student engagement as compared to that of learning as few mentioned graded assignments as part of observability.

Additional Influences

Following the instructors' completion of the DOI characteristics activity, instructors were asked if they thought there were other factors that influenced their implementation of RBIS. Additionally, there were a number of influences that were discussed throughout the interviews that were referenced for increasing or decreasing faculty adoption of RBIS.

University Support

Instructors were specifically asked about the support they receive for innovative teaching from their department and university. Some instructors discussed a very supportive environment where they were encouraged to be innovative in the classroom, "[I]n terms of innovative things like that [a new problem based learning module], the institution actually wants you to do those kinds of things" (C.). Others reflected a more non-prohibitive environment where the instructors were left to their own devices and not prohibited by the university: "The department is pretty free to let me do whatever I want" (H.), "In one way [the college] support[s] us by not having anything to do with us, I guess. You know, there's no, there aren't mandates about what you should be doing, in any way whatsoever. And so when we, you know, want to do something in a different way, there's no one saying we can't do that" (M.).

There were very few instructors that felt like innovative practices were inhibited due to promotion and tenure practices. One instructor commented, "[Y]ou're probably going to encounter resistance, and you'll be warned not to do these things. Be like [the promotion and tenure committee], because they can only reward what they understand, and they don't understand these new, innovative things. They're, they've already made it, so they don't, they're not motivated to do new, innovative things, and so they're not going to reward it" (E.). None of the interview participants expressed a resistance from his or her department or university with regards to their teaching practices, but many did reflect on indifference from the department or university that neither supported nor discouraged the use of innovative teaching practices.

A few interview participants listed additional university resources, such as centers for teaching and learning or financial support, which aided them when implementing new techniques in their classrooms. One instructor was extremely active with the Center for Teaching and Learning at her university directly citing that as "the reason why I keep putting [innovative teaching practices] in" (H.). Another instructor commented, "faculty members regularly attend symposia that they have, and myself, that was actually part of my development" (J.). He goes on to give credit to the Center for helping him develop the active learning components that he uses in his class. These Centers can be a valuable resource for faculty members to develop their teaching, but also a possible avenue for researchers to disseminate their research to connect it to the classroom.

Inertia

Another barrier that instructors identified for implementation was the inertia of not currently having innovative teaching practices. One instructor stated, “The biggest inhibitor to doing new things is just inertia, the fact that we get so used to doing things the way we do them” (A.). Wanting to maintain current practices and an desire to not change, was a barrier mentioned by several instructors saying things like: “I think in general… people don’t see the Relative Advantage over lecturing, especially if they’ve taught by lecturing for a very long time” (M.) and “People look at that and going, you know, especially if the faculty have been around for a while, look, I've been teaching this subject for X years. You know, you want me to change? You know, we all know how big humans are for change. You want me to change?” (L.). To change the teaching practices at many universities, the inertia of lecturing must be overcome, which can be a large barrier.

Discussion

From the survey results, a majority of instructors indicated some awareness of RBIS, but a number of instructors had not tried an RBIS or had discontinued use after trying an RBIS. A number of barriers were also revealed through the interviews. Every DOI characteristic (Relative Advantage, Compatibility, Complexity, Trialability, and Observability) was viewed as a barrier to RBIS adoption by some participants. Though the individual Statics instructors carried separate opinions of the Relative Advantage of the different RBIS groups, patterns emerged from my data. For example, many instructors felt RBIS were aligned with how learning happens, but there was generally one RBIS group they believed was not compatible (which varied between each instructor). Typically, Trialability and Complexity were marked as significant barriers to implementation, with many instructors citing time constraints, class size, and characteristics of the different RBIS groups in their reasoning. Observability was the most broadly discussed barrier with the instructors not generally associating the barrier with a specific RBIS groups, but citing a lack of data, knowledge of evaluation methods, and a uniform objective for RBIS. In addition to the DOI characteristics, university support was often discussed as neither a support nor a barrier for RBIS use. However, Centers for Teaching and Learning were cited by multiple of faculty members as positive influences on using RBIS in their classrooms. Also, the idea of instructor inertia, developed from the interviews, posits that one of the biggest barriers to instructors is the challenge of changing current practices, not necessarily the DOI characteristics.

Table Activity Discussion

The interview participants completed the table activity as part of the interviews, which became an important component to this study. One of the important elements of this activity was not only using a theory (DOI) to explore a phenomenon, but making the participants aware of said theory and asking them to evaluate its components. This offers a unique interpretation of the theory from the perspective of the practitioners, reversing the traditional research to practice application paradigm. Rather than collecting the data from the participants and applying theory to that data, the practitioners were given the theory to collect their interpretation of its application on their practices. This perspective can aid in bridging the gap between research and practice by integrating the views of the practitioners into the interpretation and application of the theory.

Another important element of having instructors work through this activity was that it provided a solid foundation to probe participants about their views of how to implement RBIS and the challenges they see versus the challenges researchers and RBIS developers see. This activity provided a venue and structure to help instructors verbalize their reasoning and views on the relationship between the RBIS and the DOI characteristics.

In future implementations of this activity, it is advised to prompt the participants after they make a decision and mark every box. To keep some of the interviews within the scheduled time (when instructors had other meetings scheduled after the interview), some of the decisions were left unexplained leaving an opening for more rich data to be available in the future. Also, the interviewer's clarity when explaining the instructions to participants and explanations of how to complete the activity improved as the interviews progressed. Pilot interviews are recommended for practice for other researchers and interviewers looking to use a similar technique.

Two other caveats were also revealed through the table activity. The first was something I have labeled "I do it" bias. A large number of interview participants would mark an RBIS as completely beneficial because they felt they were using the RBIS in their classroom. When explaining their reasoning, they would make comments like: "It's easy because I do it", "I know it works because I do it", or "I see it work because I do it." The fact that the instructors had already implemented the RBIS in the classroom, they did not see any of the DOI characteristics as barriers.

The second caveat is that there were a large number of interviewers that commented that certain RBIS were not appropriate for implementation in Statics. Many of the Self-Regulated Learning RBIS were thought to be more beneficial for more mature students farther along in their academic careers (i.e. seniors and graduate students). This caveat was not fully captured by the DOI characteristics but did have a strong presence in the data.

Diffusion of Innovation Discussion

While analyzing the results of this study, there were a few challenges to working with the Diffusion of Innovation framework while not targeting a new physical technology. DOI has been used repeatedly for educational and other innovative practices; however, when the instructors were discussing the DOI characteristics, Trialability and Observability were more challenging to directly apply to the classroom. Trialability was difficult for the instructors to evaluate because it was not a piece of technology that could be tested in a store before purchasing. In order to try these RBIS, instructors must dedicate time to prepare each RBIS for implementation in *their* classroom; this requires more commitment than with a traditional technology-based innovation. However, though it requires more time, many instructors indicated that it would be feasible to try an RBIS once, which could potentially be an avenue for increasing adoption. By offering instructors an opportunity to just “try” an RBIS one time with the support of the RBIS developer(s) or the Center for Teaching and Learning at their university, instructors may potentially overcome their initial trepidation of using and RBIS, which could help them using them more regularly in the classroom.

In addition to Trialability, Observability is more challenging with an RBIS than with traditional technological innovations: it is harder to see the benefits of using an RBIS right away. It is not like a cell phone for which many people can see the benefits of being able to make a phone call at nearly any location; in the case of an emergency or car trouble, the phone user can call for help. Observations such as this are more tangible when encouraging technology to be adopted and not always available when trying to encourage innovative teaching practices. When discussing Observability, the barriers that emerged were lack of “data,” lack of knowledge of assessment methods, and a non-uniform RBIS objective. These barriers can be viewed as interrelated as instructors have trouble collecting data because they are unsure about the appropriate methods to use. One of the reasons they are not sure about the methods to use is because they have varied views with regards to the objective of RBIS. Knowledge of assessment techniques is a serious barrier to adoption, but is potentially fixable through faculty development and the aid of the educational research community. For example, researchers could aid instructors by discussing the objectives they see as achievable through RBIS use when working towards implementation. Also, including training for simple evaluation methods for instructors could reduce barriers and increase adoption. A final recommendation would be to give potential adopters access to previous data on the effectiveness of an RBIS for them to evaluate the success of an RBIS for themselves.

Complexity was noted in the results as the DOI characteristic that is most commonly noted as a barrier to implementation. Where the Complexity of an innovation can increase the difficulty of implementing an RBIS, it is a very easy decoy for instructors to focus on and cite as a barrier to implementation. The real reasons for not adopting an RBIS may be more implicit beliefs about teaching and learning that would align more with Relative Advantage or Compatibility than Complexity; this became more apparent when participants would reference Complexity barriers, such as time and class size, when discussing all of the other characteristics. In addition, a number of faculty members felt RBIS they were using were less complex; showing that since they saw the advantage or found the RBIS compatible with their views on learning, the barriers of implementation were overcome with limited Complexity. A future study should more explicitly explore the teaching beliefs of instructors and the advantages instructors see to using not only RBIS, but also their teaching style in general, without the red herring of Complexity to further the investigation into the barriers to RBIS implementation.

Compatibility was also marginalized within many instructors' explanations of the RBIS barriers. As mentioned above, instructors were much more direct about explaining the complexity of why they could not implement a specific RBIS than explaining their beliefs and past experiences with teaching that influence adoption. Again, I think a direction for future research should be to more directly investigate instructors' views on teaching and how that influences their adoption practices.

Interviewer Interpretation and Discussion

From the results, there is a need to ensure that there is variety when developing new RBIS. Each of the instructors had different views on each RBIS; some relating to one group and not really "getting" another. Overall, RBIS do not need to be developed to aid all instructors; not all instructors are going to agree with them or want to use a particular RBIS. There needs to be a variety of techniques for instructors to choose from that all improve learning when implemented correctly. This result also highlights and reinforces that not every RBIS is intended every instructor. Even the most active instructor would face a challenge trying to implement all nine of these RBIS in their classroom on a regular basis. Therefore, in addition to having a variety of RBIS, it could be beneficial to aid faculty members in implementing one RBIS they relate to instead of exposing them to nine different RBIS without specific aid for implementation.

Participants mentioned time repeatedly as a large barrier to implementation; however, their estimation of the class time needed to implement certain RBIS was not always aligned with the RBIS literature. For example, Think-Pair-Share was repeatedly referenced as taking up too much class time, but is intended to take 5 minutes or less according to the literature (Felder & Brent, 1999). The disjoint between the practitioners' views and the research literature illustrates the gap between research and practice. Again, enabling more implementation training in addition to awareness presentation may help to overcome the apparent barriers that were not intended by the literature.

Class size was also repeatedly discussed as a barrier. The literature discusses that some RBIS were developed to help students engage in large classes (Felder & Brent, 1999), but that was not reflected in the interviews. The impact of very small classes was a new perspective identified through the interviews but not commonly discussed in the literature. If a class is too large, implementing certain RBIS becomes more challenging. However, when the classes are less than 10 students, there is a different set of challenges. RBIS developers should be aware of the influence both a large and small class size can have on RBIS implementation. When discussing RBIS implementation with a large group of instructors, specific tips should be given for how to implement each RBIS on a large, medium, or small scale. Each instructor teaches in a different context that influences how they are able to implement each RBIS and this should be reflected in RBIS training.

Conclusion

This study examined the familiarity of Statics instructors with nine RBIS and the barriers Statics instructors perceive to implementing RBIS in the classroom. A majority of instructors indicated at least some awareness of RBIS, but a number of instructors had not tried an RBIS or had discontinued use after trying an RBIS.

A number of barriers were also revealed through the interviews. Each DOI characteristic (Relative Advantage, Compatibility, Complexity, Trialability, and Observability) was found to present a barrier to RBIS adoption. The individual Statics instructors carried separate opinions of the Relative Advantage of the different RBIS groups. Many instructors felt RBIS were aligned with how learning happened, but there was generally one RBIS group they believed was not compatible. Trialability and Complexity were marked as significant barriers to implementation, with many instructors citing time constraints, class size, and characteristics of the different RBIS groups in their reasoning. Observability was the most broadly discussed barrier with the instructors not generally associating the barriers with a specific RBIS groups, but a lack of data, knowledge of evaluation methods, and a uniform objective for RBIS.

In addition to the DOI characteristics, university support was often discussed as neither an encouragement nor a barrier for RBIS use. However, Centers for Teaching and Learning were cited by a number of faculty members as positive influences on using RBIS in their classrooms. Also, the idea of instructor inertia developed through the interviews, indicating that one of the biggest barriers to instructors not using RBIS is that they have not used them in the past and they do not wish to change their teaching practices.

Implications for practice

One of the goals of this research study was to aid in bridging the research to practice gap by identifying the practitioner's perspective of the research. From these perspectives, it is hoped that a dialogue can develop between researchers and practitioners that will help researchers disseminate their findings while helping practitioners overcome the barriers they face when attempting to implement new instructional strategies in the classroom.

In relation to bridging the research-to-practice gap, using instructor identified barriers from this study, faculty development change agents can directly target the barriers instructors are facing. This may require large adjustments to training materials (including tips for teaching to a variety of class sizes), but may also include simple changes like adjusting the emphasis put on some aspects of certain RBIS while increasing the emphasis on addressing barriers (Think-Pair-Share is meant to take 5 minutes of class time).

Future Direction for Research

There are a number of directions for future research related to this study. One is investigating whether instructors are spending class time on the associated activities that are needed to be implementing RBIS when they indicate that they are using an RBIS; this is investigated more extensively in K-12 education settings as the Fidelity of Implementation. Future research should explore the implication and applications of this framework on RBIS implementation in higher education.

Another direction for future research is to investigate the influence of the *social system* on RBIS implementation; this major DOI element was not directly explored in this study but the instructors discussed the influence of their departments (*social system*). Though the results of this study found that university support had a neutral influence on instructor's decision to adopt, the *social system* element may potentially be able to act as a positive influence on adoption. Also, each faculty member is part of a variety of social systems. It would be interesting to investigate the influence of outside the university social systems (i.e. professional organizations) on instructor's decisions to adopt.

One of the findings of this study was that instructors face different barriers to implementation based on the class they are teaching, e.g. "This is not appropriate for Statics." A future study could explore a variety of other courses to explore the more common barrier that all instructors face regardless of the course content and which RBIS are more appropriate for which courses.

Finally, future research could benefit from classroom observations of instructors to observe their teaching styles, as one of the limitations of this study is the self-reported nature of the data. By observing instructors in the classroom, the current innovative practices they implement in their classroom may influence how they approach new innovations and may offer insight into why they choose to use one RBIS over another.

This research investigates the barriers that instructors face when implementing Research-Based Instructional Strategies in the Statics classroom. There are number of barriers instructors face and continuing to understand and overcome these barriers can aid in bringing research-based discoveries into the classroom, closing the research-to-practice gap.

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Chapter 4

Manuscript 3: Fidelity of Implementation in the Statics Classroom

Portions of this manuscript (an abbreviated literature review and the results of 3 RBIS) were accepted to the 2013 annual American Society for Engineering Education Conference in Atlanta, GA

The audience for this article is the engineering education research community. This study is meant to present a new framework for engineering education research as well as begin a new conversation within the community about Fidelity of Implementation. The ASEE conference was chosen to directly reach the engineering research and begin the conversation directly with them at the conference.

Abstract

Many teaching innovations have been developed over the last 20 years, including a number of Research-Based Instructional Strategies (RBIS). However, there is limited research to address if faculty members are using these strategies, or whether they are following the theory and steps as intended by the developers when they do implement them. The measure of how well an implemented intervention follows the original intent is called Fidelity of Implementation. I sought to understand Fidelity of Implementation in engineering Statics courses using a national survey of Statics instructors. Their reported use of eight RBIS was compared to their reported use of classroom activities identified as critical components corresponding to RBIS use. Critical components for each RBIS were identified and examined as to whether they were implemented in conjunction with the various RBIS and whether they discriminated between users and non-users.

To quantify Fidelity of Implementation for the different RBIS, the percentage of required critical components implemented in conjunction with each RBIS was examined. Use of all critical components for the given RBIS varied from 3-83%. Higher percentages (65-83%) were associated with RBIS that had just one required critical component, including Active Learning and Concept Tests. For RBIS with higher numbers (3-5) of required critical components (Problem Based Learning, Peer Instruction, Collaborative Learning, Think-Pair-Share, and Cooperative Learning), it was observed that though the percentage of users with complete fidelity (all critical components) was low (3-66%), the percentage that used zero components was also low.

To measure the discriminating ability of the critical components, a Chi Square was completed comparing RBIS users and non-users with respect to the different components they indicated spending time on. A number of RBIS (Active Learning, Collaborative Learning, and Concept Tests) had significant differences between users and non-users for all of the required components. There were also a number of classroom activities that were not considered critical components for a particular RBIS that also had a significant relationship, which may indicate adaptations of certain RBIS that were not considered in the literature.

Introduction

Over the past several decades, there has been a constant need to reexamine the way the next generation of engineers is being educated. With the engineering profession continually changing, the skills that engineering students need to be prepared have also changed (National Academy of Engineering, 2004). University instructors are being called on to reform their teaching. The ABET learning outcomes (ABET Inc., 2009) have shifted what is being taught in the classroom while the National Research Council is calling for a change in teaching methods (National Research Council, 2012). One way researchers are aiding in this effort is through the development of Research-Based Instructional Strategies (RBIS), such as active learning, cooperative learning, and inquiry learning, for implementation in the classroom.

In recent years, researchers have begun working to investigate whether these Research-Based Instructional Strategies (RBIS) are being used in the engineering (Borrego, Cutler, Froyd, Prince, & Henderson, 2011; Cutler, Borrego, Henderson, Prince, & Froyd, 2012; Froyd, Borrego, Prince, Henderson, & Cutler, 2012; Michael Prince, Borrego, Henderson, Cutler, & Froyd, 2012), as well as physics (Henderson, Dancy, & Niewiadomska-Bugaj, submitted 2012) and geosciences

(Medina-Borja, Pasupathy, & Triantis, 2007), classroom. The results of these studies show an encouraging level of adoption among faculty members. However, more work is needed to investigate if faculty members are using consistent language and activities when discussing the use of each RBIS.

Clear, consistent terminology is needed for each RBIS. Currently, within the RBIS literature, each RBIS is discussed with slight differences and varying characteristics, such as the distinction between cooperative and collaborative learning or between problem-based learning and project-based learning. To minimize confusion, there should be agreed upon characteristics for each RBIS that ensures it is being used correctly. These characteristics can also help define which characteristics are necessary to realize the benefits of increased learning and engagement.

RBIS are also “research-based” and are, therefore, developed by researchers and often discussed as research topics. As a result, efforts are needed to ensure that RBIS are discussed in ways practitioners can understand and implement. Again, developing and defining specific activities to be done in the classroom can help bridge the gap between researchers and practitioners.

To address these concerns, I referred to the K-12 educational literature. Within K-12, there are much more explicit needs to ensure that programs follow specified guidelines that meet state and federal requirements (Century, Rudnick, & Freeman, 2010; O'Donnell, 2008). Within K-12 evaluation, it is common to include an element called the Fidelity of Implementation, or how well the implemented innovation follows the original intent (O'Donnell, 2008). Fidelity of Implementation provides evidence that the intended innovation or intervention is being implemented and the impact of any changes are documented and tracked, which is not required in higher education due to the freedom faculty members have to control their own classrooms. I am not suggesting that complete or full fidelity is necessary in all contexts. Instead, the terminology and discussion of these RBIS should be made more explicit. There have been limited studies investigating Fidelity of Implementation within engineering education (exceptionBorrego, Cutler, Prince, Henderson, & Froyd, accepted).

This study uses the Fidelity of Implementation framework to investigate the implementation of RBIS within the Statics classroom, addressing the following research questions:

- With what degree of fidelity are Research-Based Instructional Strategies (RBIS) being implemented within the Statics classroom?
- Do the critical components that characterize an RBIS discriminate between Statics faculty members who claimed use of RBIS and those who did not?

I chose to focus this study on Statics, as Statics is a fundamental engineering sciences course for multiple engineering disciplines. Engineering sciences courses, like Statics, are introductory courses that are prerequisites for upper level engineering courses, such as dynamics and mechanics of materials (Streveler, Litzinger, Miller, & Steif, 2008). Also, engineering sciences courses have been neglected in the RBIS literature, unlike first-year or senior design courses.

To investigate these research questions, I used a national survey of Statics instructors. Their reported use of nine RBIS (listed in Table 2) was compared to their reported use of classroom activities identified as critical components corresponding to RBIS use. Critical components for each RBIS were identified and examined as to whether they were implemented in conjunction with the various RBIS and if they discriminated between users and non-users.

Literature Review

According to Rogers, early dissemination studies were based on the implicit assumption that all adoption was “an exact copying or imitation of how the innovation had been used previously in a different setting” (2003, p. 174). More recently, it has become clear that studies must also consider the extent to which the innovation changes during the diffusion process, so researchers have begun considering the Fidelity of Implementation.

A high level of fidelity has obvious benefits with regards to being able to measure and trace diffusion of an innovation (e.g. a specific teaching strategy). However, adopters (particularly engineering faculty members) often need to modify the innovation in order for it to work in their environment. Some level of adaptation is desirable because it promotes adoption and may also improve upon the innovation (Rogers, 2003). Work in Fidelity of Implementation is beginning to consider these issues systematically but debate continues about the extent to which an innovation should be allowed to change (Blakey, 1987; Century et al., 2010; Emshoff et al., 1987; Hall & Loucks, 1978; Mowbray, Holter, Teague, & Bybee, 2003; O'Donnell, 2008).

Fidelity of Implementation is broadly defined as the measure of how well an implemented intervention follows the original intent (O'Donnell, 2008). While there is limited engineering education research that specifically investigates Fidelity of Implementation, fields such as mental health (Bond, Evans, Salyers, Williams, & Kim, 2000), program evaluation (Bickman et al., 2009; Emshoff et al., 1987; Rohs & Vartuli, 2009), education (Dusenbury, Brannigan, Falco, &

Hansen, 2003; Mills & Ragan, 2000; O'Donnell, 2008; Telzrow, McNamara, & Hollinger, 2000), and human services (Blakey, 1987; Dusenbury et al., 2003; Emshoff et al., 1987; Fagan, Hanson, Hawkins, & Arthur, 2008) have been conducting such investigations for several decades (Mowbray et al., 2003).

There are typically two types of fidelity studies: efficacy studies and effectiveness studies. Aspects of both are relevant to our study of Statics education. Efficacy studies investigate whether an intervention can achieve the set objectives under ideal circumstances. An "Efficacy study's examination of fidelity focuses on whether a program is implemented at all… and to what degree… and it uses the answers to these questions to improve the program" (O'Donnell, 2008, p. 41). Efficacy studies typically focus on the development stage and help developers critically analyze the component needed for the innovation to succeed. Many engineering education researchers, particularly those developing curricular materials or instructional strategies, conduct efficacy-type studies. For example, when researchers expand their work to include other student populations at other institutions, they are trying to better understand the exact conditions under which their interventions improve student learning.

In contrast, an effectiveness study investigates the effects of an innovation when implemented by regular users in actual practice. "Effectiveness studies seem more interested in interpreting evidence of the program for generalizability…and observing the implementation of the program in the field" (O'Donnell, 2008, p. 42). With effectiveness studies, the focus shifts from the level of fidelity needed for the intervention to be successful to the changes that users make in practice and the impact of these changes on the ability of the intervention to achieve its goals. The current study is an effectiveness study because it is investigating how Statics instructors are using RBIS.

However, fidelity is a relatively new concept in undergraduate STEM education and previous efficacy studies on RBIS did not contain a fidelity element. Therefore, this paper discusses a number of elements typically considered in efficacy studies, such as identification of critical components. For further discussion and examples of efficacy and effectiveness studies as well as a general review of Fidelity of Implementation research, see (2008).

A key element of fidelity is the components that characterize the intervention. Century and colleagues called these the *critical components*, defined as the “essential features that must be measured to determine whether a program is present or not” (2010). Similar to engineering specifications used in the design process, critical components help indicate whether the intervention does what was intended. Critical components are similar to the *components* in the Concerns Based Adoption Model’s (CBAM’s) innovation configurations. Mowbray and colleagues refer to them as *fidelity criteria* (2003), Carroll calls them *essential components* (2007) and Bickman and coworkers label them *fidelity measures* (2009). Despite the variations in terminology, each of these perspectives focuses on identifying the components that are necessary for fidelity. In this study, I will refer to them as *critical components*. Efficacy studies develop the critical components while effectiveness studies investigate whether the critical components are present or have been changed. In order to conduct an effectiveness study, I must first determine the critical components of the RBIS of interest.

The steps to identifying critical components are laid out in CBAM’s innovation configuration literature (Hall & Loucks, 1978). Developing an innovation configuration begins with a literature review of the innovation, followed by an iterative process that includes user interviews and observations. Next, the component checklist is constructed, which includes all of the components and variations of each component. The final step is locating dominant patterns by categorizing individual users (from earlier interviews) by the variations they use. As a result, the list may be revised. The level of fidelity in a particular setting can then be quantified by dividing the number of components implemented by the total number of components. For examples of fidelity research that have used CBAM, see (1997), (1987), and (2000).

The process of establishing an innovation configuration is a significant undertaking; it is usually performed by the developer of the innovation and rarely, if ever, done for more than one intervention at a time. For the purposes of this study, in which I am comparing nine RBIS, I have abbreviated the process to include an extensive literature search and consensus among a panel of engineering and physics education experts. However, I note that systematically identifying critical components through innovation configurations or other means is an important direction for future work, particularly among the developers of new research-based instructional strategies.

Mowbray and coworkers (2003) reviewed the literature on Fidelity of Implementation to identify common steps used to establish, measure, and validate the fidelity criteria of an innovation; these steps are outlined in Table 1. The first step is to establish critical components. The three most common ways of establishing critical components are: (1) using an established program model (which already lists critical components), (2) using the expert opinion of those who have published on the innovation, and (3) using qualitative research methods such as interviews with users. These are abbreviated steps that reflect CBAM's innovation configuration. For this study, I relied on the literature, augmented by the expertise of an advisory board of researchers with backgrounds in the development and implementation of RBIS (which included authors of the most highly cited articles related to RBIS in engineering).

Table 1: Mowbray, et al.'s (2003) steps to evaluate Fidelity of Implementation. Italics indicate methods used in this study.

Steps	Methods to accomplish each step
1.Establish Critical Components	Established program's model (listing components) ***Literature/Expert Opinion*** Qualitative research methods (e.g., user interviews)
2.Measure Fidelity	Researcher/expert ratings from observations or documentation ***User surveys*** User interviews
3.Validate Fidelity Criteria	***Inter-rater reliability*** ***Comparison of actual to expected results*** Comparison across known groups/programs Comparison of fidelity to efficacy measures ***Convergent validity of multiple sources***

Once critical components have been identified, the next steps are to measure fidelity and establish validity (Mowbray et al., 2003). The measurement of fidelity can be accomplished through (a) researcher or expert ratings of observations or other implementation documentation, (b) user surveys or (c) user interviews. In this study, I surveyed engineering science faculty members about their classroom activities and RBIS use. Then, validity and reliability of the criteria can be established utilizing one or more of the following methods: ensuring inter-rater reliability; confirming consistency of the internal structure between expected and actual results; ensuring convergent validity by using multiple sources; using known groups to compare across programs; and comparing the observed fidelity measures to the expected outcomes of the user (e.g., student learning gains). When establishing the critical components in this study, the advisory board ensured inter-rater reliability by discussing and refining the set of critical components until all members reached an agreement. Additionally, I surveyed faculty members from multiple universities and engineering disciplines to compare fidelity across settings.

Throughout the results section and in the discussion that follows, I compare the actual results to the expected results and consider implications for fidelity criteria.

Methods

Survey

Development of Critical Components

Following (1978) and (2003), critical components for each RBIS were developed. To begin, I consulted the literature base of each RBIS. Many of these either went back to the original development of each RBIS or the researchers that became strong advocates for adopting the RBIS. I consulted an external advisory board including Maura Borrego, Michael Prince, Jeffrey Froyd, and Charles Henderson. Each of these researchers have completed numerous investigations into RBIS use. They were asked to compile a list of activities that fully explained each RBIS. The board achieved consensus on a list of “required” and “indicative” critical components for each RBIS, which I then compared again to the literature. Required components represent activities that would be absolutely necessary to claim that a certain RBIS is being used. For example, having students discuss problems in pairs is required for Think-Pair-Share. Indicative components represent activities generally associated with RBIS use but not required by the literature. For example, discussing problems in pairs is frequently indicative of active learning, but is not required for active learning to be used. The developed critical components were based on the advisory board’s and my interpretation of each RBIS from the literature. The developers of each RBIS were not consulted directly, although many were authors of the literature cited. The final list comprised 16 activities; many of which correspond to multiple

RBIS. This mapping is presented Appendix E. A full list of the activities, RBIS, and the critical components can be found in Appendix F.

Table 2: Research Based Instructional Strategies (RBIS) and descriptions used in the survey.

RBIS	**Brief Description**
Just-In-Time Teaching	Asking students to individually complete homework assignments a few hours before class, reading through their answers before class and adjusting the lessons accordingly.
Inquiry Learning	Introducing a lesson by presenting students with questions, problems or a set of observations and using this to drive the desired learning.
Peer Instruction	A specific way of using concept tests in which the instructor poses the conceptual question in class and then shares the distribution of responses with the class (possibly using a classroom response system or "clickers"). Students form pairs, discuss their answers, and then vote again.
Concept Tests	Asking multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions.
Think-Pair-Share	Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions. After that, calling on students to share their responses.
Problem-Based Learning	Acting primarily as a facilitator and placing students in self-directed teams to solve open-ended problems that require significant learning of new course material.
Collaborative Learning	Asking students to work together in small groups toward a common goal.
Cooperative Learning	A structured form of group work where students pursue common goals while being assessed individually.
Active Learning	A very general term describing anything course-related that all students in a class session are called upon to do other than simply watching, listening and taking notes.

Instrument

The survey instrument was adapted from a previous survey of introductory physics instructors (Henderson & Dancy, 2009; Henderson, Dancy, & Niewiadomska-Bugaj, in press) as well as a survey of electrical, computer, and chemical engineering instructors (Borrego et al., 2011; Borrego et al., accepted; Cutler et al., 2012; Froyd et al., 2012; Michael Prince et al., 2012).

The instrument was divided into five sections (Shown in Appendix A). The first section asked when the last time the respondent had taught Statics was. The second section asked respondents about their teaching and learning beliefs. The third section asked respondents to estimate the amount of class time spent on different activities generally associated with RBIS use—the required and indicative critical components. The fourth asked respondents about their level of use and knowledge of the nine specific RBIS; the descriptions in Table 2 were included. The fifth section included demographic information such as gender, rank, and frequency of attendance at teaching workshops. Cronbach's alpha was calculated as 0.9208 to ensure reliability of the instrument, which indicated a level of reliability well above acceptable (Pedhazur & Schmelkin, 1991).

Data Collection

Statics instructors were identified by compiling a list of all accredited U.S. mechanical engineering programs (n = 285). The list also included 7 civil engineering and 4 aeronautical/aerospace engineering programs at institutions that do not offer mechanical engineering. The Virginia Tech Center for Survey Research (CSR) staff contacted each department via telephone with email follow-up to identify the Statics instructors. The protocol included identifying which department was responsible for the course and following up as appropriate. Each instructor was invited to complete the survey via a personalized e-mail signed by Paul Steif and Anna Dollár, established Statics professors and researchers. The survey was administered in fall 2012. The survey was administered in fall 2012 to 764 faculty.

Responses were screened to ensure respondents had taught Statics within the last five years and had completed a majority of the survey items. Any participant who did not meet these characteristics was removed from the analysis. Out of the 205 initial responses, 166 Statics were usable.

The Statics survey was sent to 764 faculty members with 166 responses and a response rate of 22%. Of the 166 usable responses, 20% of respondents were female and 62% male (18% did not respond); 13% were lecturers (i.e., not tenure track), 17% assistant professors, 25% associate professors, 17% full professors, and 10% listed their position as other (18% did not respond). The respondents came from a variety of engineering departments or programs: 34% mechanical engineering, 34% civil, 5% aerospace/aeronautical, 2% engineering mechanics, and 7% indicated “other” (18% did not respond).

Data Analysis

I operationalized an RBIS user as someone who indicated that they were currently using a specific RBIS (responded “I currently use it”). A non-user is an instructor who is not *currently* using the specific RBIS (responded any other way to the item). The multiple choice options for the RBIS section included just one option for current use; all other responses were considered to indicate non-users. I operationalized that an instructor spent time on an activity if they indicated spending more than 0% of class time on the activity. Due to the varying nature of each RBIS, some activities are meant to only take 1 or 2 minutes of class time which is less than 25% of class time. Instructors were not spending class time on an activity if they spent 0% of class time on the activity. The prompt for the activities was, “Please indicate what percentage of time on average your students spent/spend on each of the activities below during class time.” The options were: 0%, 1-25%, 26-50%, 51-75%, and 76-100%.

Fidelity of Implementation was operationalized as the percentage of RBIS users who also spent class time on the required critical component(s). However, the advisory board identified between 1 and 5 required critical components for each RBIS. In the results section, I report the percentage of RBIS users who spent time on 0 to 5 required components (as relevant).

Since all respondents answered questions about which classroom activities they spent time on, I also used this data set to determine whether various critical components were useful for discriminating between RBIS users and non-users. Due to the categorical nature of the data (multiple choice responses within the survey), a nonparametric test was required. Chi Square is a common non-parametric test that compares the frequency of responses for separate groups (Crocker, 1981). A Chi Square or Fisher's Exact (used when responses for one group was less than five (Crocker, 1981)) test was used to examine the relationships between two groups of respondents (users and non-users) (Bartz, 1976; Cohen & Holliday, 1979). In this study, the Chi Square enables us to compare the number of survey respondents who indicated using a specific RBIS and spending time on a given critical component to those who *did not* indicate using the RBIS (non-user) and spending time on the same critical component. (unless indicated, all results are Chi Square).

Chi Square tests the null hypothesis that both the user group and the non-user group have an equal number of respondents spending time and not spending time on each critical component (Crocker, 1981). For example, there is no relationship between Collaborative Learning and having "students work on a problem in pairs or groups," if the p-value is less than alpha (0.01 due to the large number of comparisons being made in this study). The low p-value indicates that the null hypothesis should be rejected indicating there is a relationship between use of that specific RBIS and the critical component (Bartz, 1976; Cohen & Holliday, 1979; Crocker, 1981). In other words, when an activity is "required" or "indicative" for a specific RBIS, a p-value less than 0.01 is expected to indicate discrimination between users and non-users. (It is also possible that both users and non-users have a similar level of use that is not statistically significantly different, which could indicate high Fidelity of Implementation without strong discrimination between RBIS users and non-users.)

Interviews

Interviews were conducted with 18 Statics instructors from 11 institutions in the state of Virginia. Fidelity was included as an *a priori* code for the qualitative analysis of the interviews (Tashakkori & Teddlie, 2003), but few passages were included as part of this code, limiting the amount of qualitative results that will be presented in the results. The qualitative methods implemented in this study are being used to help support the quantitative results, specifically targeting the unexpected relationships between activities not designated as critical component and a specific RBIS. A more extensive discussion of the qualitative methods used here can be found in (Manuscript 2).

Limitations

The limitations of this faculty survey approach include response bias from particularly conscientious instructors and self-report of RBIS use. Both tend to overestimate the level of RBIS use. However, the goal of this analysis is not to determine the proportion of engineering faculty members using RBIS. Rather, this analysis is focused on engineering faculty members' understanding and adaptation of RBIS, many of which were not developed in engineering.

Additional responses from faculty members who do not use RBIS, though likely more representative of the population, would have been of little use here.

Also, this analysis did not investigate unintentional Fidelity, where someone using all of the critical components, but not indicating that they are using the specific RBIS. This may influence the critical component's ability to distinguish between users and non-users. However, this study is meant to be an initial investigation to begin the conversation about fidelity, and future work should investigate if RBIS are being used without the name and implications of this inverted relationship.

Results and Discussion

The discussion of the results has been broken into two sections. The first looks at the number of required critical components that RBIS users are spending time on in their classroom. The second uses Chi Square analysis to examine the critical components ability to discriminate between RBIS users and non-users.

Fidelity of Implementation: Percentage of users spending time on critical components

To evaluate the Fidelity of Implementation for RBIS, I first looked at the percentage of users who were also spending time on the required critical components. Table 3 shows high levels (more than 60%) of fidelity for many of the RBIS.

Table 3: The percentage of RBIS users who spend class time on required critical components

	% of RBIS users who also spend time on critical components					
Number of Required Critical Components	**0**	**1**	**2**	**3**	**4**	**5**
Problem Based Learning	0%	0%	5%	11%	21%	63%
Peer Instruction	0%	0%	7%	38%	55%	
Collaborative Learning	0%	2%	32%	66%		
Think-Pair-Share	0%	0%	38%	62%		
Cooperative Learning	0%	0%	46%	54%		
Concept Tests	17%	83%				
Just-in-Time Teaching	23%	77%				
Inquiry Learning	35%	65%				

RBIS with one required critical component (Concept Tests and Just-in-Time Teaching) had more than 75% of the users also spending time on the required critical component. Inquiry Learning was slightly lower (65%), but still well above half. However, the challenge with these RBIS is that the fidelity is either all or nothing; either they are using "all" (1) of the critical components or none. So where 65% of Inquiry Learning users had complete fidelity, 35% of users are using this RBIS with no fidelity.

RBIS with multiple components had slightly lower percentages of complete fidelity percentages (3% - 63%), and they had much lower percentages of users not using any of the critical components (0%). Most faculty members (93% - 100%) indicated using at least half of the components, which shows some level of fidelity though not complete. There are many arguments regarding acceptable levels of fidelity. For the purposes of this exploratory study into Fidelity of Implementation, the high number of respondents who are using a majority of the components is encouraging. Further research is needed to investigate which components are often absent from implementation and the impact of neglecting those components on the effectiveness of the strategy.

Fidelity of Implementation: The discriminating power of critical components between users and non-users

The next section of the results will discuss each RBIS and the associated critical components. I will focus on discussing the differences between users and non-users spending time on critical components. Again, the critical components are separated into required and indicative components. Required components are activities that would be absolutely necessary to claim that an RBIS is being used. For example, having students discuss problems in pairs is required for Think-Pair-Share. Indicative components are generally associated with RBIS use, but are not required by the literature. For example, discussing problems in pairs is frequently indicative of Active Learning, but is not required for active learning to be used. Both required and indicative components were tested for significant differences between users and non-users of the specific RBIS with respect to whether time was spent on the component.

Inquiry Learning

Inquiry Learning is an instructional strategy in which students are presented with questions to be answered, problems to be solved, or a set of observations to be explained (Kolb, 1984). Coller used inquiry learning in his Statics course and found that the electrical engineering students taking the course greatly benefited (as evidenced by higher exam grades) from hands-on Inquiry Learning when compared to another section that did not use Inquiry Learning (2008).

Inquiry Learning has one critical component, which did not show a significant difference between users and non-users (Table 4). However, nearly two-thirds (65%) of the faculty members reported using Inquiry Learning and completing the required activity of having students “work on problems or projects that require students to seek out new information not previously covered in class,” as compared to 49% of non-users (Table 4). There was a significant difference between users and non-users for the indicative component of having students “complete specifically designed activities to ‘learn’ course concepts on their own without being explicitly told” (Table 4), but not for the indicative component of having students “participate in activities that engage them with course content through reflection and/or interaction with their peers.”

Table 4: Inquiry Learning Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 55) and spent time on activity	Faculty who **don't** use RBIS (n = 111), but spent time on activity	p-value
Work on problems or projects that require students to seek out new information not previously covered in class	Required	65%	49%	0.041
Complete specifically designed activities to "learn" course concepts on their own without being explicitly told	Indicative	71%	50%	.009*
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	85%	70%	0.033

Just-in-Time Teaching (JiTT)

Just-in-Time Teaching (JiTT) calls for students to individually complete Web-based assignments a few hours before class. The instructor reads through submitted answers before class and adjusts the lessons accordingly (“just in time”) (Michael Prince & Felder, 2006). Cashman and Eschenbach found that JiTT increased student engagement and confidence when implemented in their Introduction to Environmental Engineering course (2003).

The critical components for Just-in-Time Teaching did not show a significant difference between users and non-users (Table 5). However, 77% of users indicated that they spent time on the required critical component of having students spend time "discussing pre-class assignments which helped [the professor] reevaluate student learning and adjust your lecture 'just in time.'" Also, 82% of JiTT users spent time on the indicative general active learning activity as well (Table 5). Again, this indicates that users are spending time on the critical components. However, the components are not specific to that one RBIS and, therefore, do not discriminate between users and non-users due to a high number of non-users also spending time on the components.

Table 5: Just-in-Time Teaching Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 22) and spent time on activity	Faculty who **don't** use RBIS (n = 144), but spent time on activity	p-value
Spent time discussing pre-class assignments which helped you re-evaluate student learning and adjust your lecture "just in time"	Required	77%	58%	0.09
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	82%	74%	0.598 [1]

[1] indicates Fisher's Exact Test used

Concept Tests

Concept Tests are multiple choice concept questions that use common student misconceptions as distracters (wrong answers) (Felder & Brent, 2009). These can be implemented in larger classes through the use of clickers or similar voting methods that require students to commit to an answer before discussing the correct answer. Santi used Concept Tests in a geological engineering course to address two common misconceptions (2007). He expressed some of the challenges to developing conceptual questions that reflect an equal level of difficulty.

There was a significant difference between users and non-users for the required activity of having students “answer multiple-choice conceptual questions with distracters that reflect common student misconceptions” (Table 6) with 90% of users also spending time on this activity as compared to 46% of non-users.

The indicative components did not show a significant difference between users and non-users. However, three of the indicative components were used by more than 85% of concept test users (Table 6). This included having students: “participate in activities that engage them with course content through reflection and/or interaction with their peers”, “provide that answer(s) to a posed problem or question before the class can proceed”, and “discuss a problem in pairs or groups.” The high percentage of users spending time on these activities shows that they are used in conjunction with concept tests and with other RBIS or in the general classroom as well. However, again, a high number of non-users are also spending time on this activity causing a non-significant difference between users and non-users.

Table 6: Concept Tests Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 41) and spent time on activity	Faculty who **don't** use RBIS (n = 125), but spent time on activity	p-value
Answer multiple-choice conceptual questions with distracters that reflect common student misconceptions	Required	90%	46%	<0.001*
Use means other than clickers to 'vote' on the correct answer of a multiple choice question	Indicative	59%	38%	0.024
Use clickers to "vote" on the correct answer of a multiple choice question	Indicative	22%	10%	0.039
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	85%	72%	0.085
Provide the answer(s) to a posed problem or question before the class can proceed	Indicative	85%	82%	0.582
Discuss a problem in pairs or groups	Indicative	90%	89%	1.00 [1]

* indicates a significant relationship with alpha = 0.01

[1] indicates Fisher's Exact Test used

Peer Instruction

Peer Instruction allows students the opportunity to respond to a multiple-choice conceptual question (generally using some sort of classroom response system), then discuss their response with a neighbor, followed by a repeated response to the question (Pilzer, 2001). Koretsky and Brooks used Peer Instruction in a thermodynamics course for chemical engineers and found that the quick feedback provided to faculty members greatly aided them in helping students address misconceptions. Also, on simple questions, they found an increase in student knowledge and understanding after completing the peer instruction exercise (2011).

Peer Instruction had moderate fidelity with 55% using all four critical components and none only using one or no critical components (Table 3). The only discriminating critical component was having students “answer multiple choice conceptual questions with distracters that reflect common student misconceptions” (Table 7).

It is concerning from a fidelity perspective to see that only 24% of Peer Instruction users also have their students “use clickers to ‘vote’ on the correct answer,” as compared to having students “use means other than clickers to ‘vote’ on the correct answer of a multiple choice question,” which had a significantly different relationship between users (66%) and non-users (39%). Many of the interview participants discussed the need for university support to use clickers as well as not wanting to provide additional financial strains on students requiring them purchase a clicker. The infrastructure support may be a deterrent of using clickers resulting in a higher percentage using other means.

Table 7: Peer Instruction Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 29) and spent time on activity	Faculty who **don't** use RBIS (n = 137), but spent time on activity	p-value
Answer multiple choice conceptual questions with distracters that reflect common student misconceptions	Required	83%	50%	<0.001* [1]
Use clickers to 'vote' on the correct answer of a multiple choice question	Required	24%	10%	0.041
Discuss a problem in pairs or groups	Required	97%	88%	0.204 [1]
Provide answer(s) to a posed problem or question before the class session can proceed	Required	86%	82%	0.788 [1]
Use means other than clickers to 'vote' on the correct answer of a multiple choice conceptual question	Indicative	66%	39%	0.008*
Report their group's findings to the entire class	Indicative	52%	37%	0.147
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	83%	74%	0.305

* Indicates significant relationship with alpha = 0.01
[1] Indicates Fischer’s Exact Test was used

Collaborative Learning

Collaborative Learning is a general term for any group work where students are working to a shared goal (Barkley, Cross, & Major, 2005). These techniques can be formal group projects or informal classroom activities in which students work with a partner. Shooter and McNeal used Collaborative Learning in their interdisciplinary Mechatronics course to help students meet ABET criterion 3 learning objectives (2002).

Collaborative Learning was considered to have moderate to high levels of fidelity with 66% of users spending class time on all three of the required critical components (Table 3). Each of these critical components was also found to differentiate between users and non-users (Table 8). "Discussing a problem in pairs or groups" was used by 97% of users and was found to be significantly different than non-users with a p-value of 0.001. Having students "work on problem sets or projects in pairs or small groups" was used by all (100%) of users and was found to have significantly different use when compared to non-users with a p-value less than 0.001. The key discriminating characteristic of Collaborative Learning is in how the assignments are assessed. In Collaborative Learning, students "participate in group work for which they earn the same score as every other member of the group." This critical component was found to be used by 66% of faculty members who use Collaborative Learning and to be significantly different between users and non-users with a p-value less than 0.001.

When considering the indicative critical components, a high percentage of users spend time on the components (66% - 89%) (Table 8). Of the faculty members using Collaborative Learning, 86% reported having students "provide answer(s) to posed a problem or question before the class session can proceed." Though a high percentage, 79% of non-users also spent time on this activity, most likely because this is a common activity with other RBIS and lecturing in general. The common critical component of having students "participate in activities that engage them with course content through reflection and/or interaction with their peers" was significantly different for users and non-users with a p-value less than 0.001. The key element of this activity that may have been stronger with users, when compared to non-users, is the latter part indicating that students have "interaction with their peers" which is strongly related to Collaborative Learning.

Table 8: Collaborative Learning Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 79) and spent time on activity	Faculty who **don't** use RBIS (n = 87), but spent time on activity	p-value
Work on problem sets or projects in pairs or small groups	Required	100%	63%	<0.001* [1]
Participate in group work for which they earn the same score as every other member of the group	Required	66%	24%	<0.001*
Discuss a problem in pairs or groups	Required	97%	82%	0.001* [1]
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	89%	63%	<0.001*
Complete specially designed activities to "learn" course concepts on their own without being explicitly told	Indicative	66%	48%	0.023
Provide answer(s) to a posed problem or question before the class session can proceed	Indicative	86%	79%	0.252

* indicates a significant relationship with alpha = 0.01
[1] indicates Fisher's Exact Test used

Significant relationships were also found between Collaborative Learning and having students "report their group's finding to the entire class (formally or informally)" with 65% of users also spending time on this activity as compared to 17% of non-users (p-value <0.001). In practice, a number of faculty members may have students complete projects as a group and give a final presentation for one score; this would explain the larger number of Collaborative Learning users also spending time on reporting group findings. In future research, it would be beneficial to investigate the relationship between this activity and Collaborative Learning to more concretely discern if this activity is a critical component of this RBIS.

Unexpectedly, Collaborative Learning was also found to have a significant relationship with having students "work on problems or projects that require students to seek out new information not previously covered in class" with 38% of users also spending time on this activity as compared to 18% of non-users (p-value = 0.005). Again, this may refer to the problem or project-based nature of Collaborative Learning and the need within that to have students seek out additional information. Further investigation is needed to determine the exact relationship between this activity and Collaborative Learning.

The last unexpected relationship was between Collaborative Learning and having students "participate in group work for which the assessments are designed so that individuals may earn different scores for their work on the assignments" with 70% of users also spending time on this activity as compared to non-users at 40% (p-value < 0.001). Collaborative Learning is not typically discussed with this activity in the literature. This relationship points to the similarities between Collaborative Learning and Cooperative Learning, which has this activity as a required component.

The similar nature of Collaborative Learning and Cooperative Learning may cause confusion for faculty members (and researchers) regarding their actual differences. Many interview participants noted the similar nature of Collaborative Learning and Cooperative Learning and asked for clarification of the differences. This is a goal of Fidelity of Implementation research: clearly stating what activities are characteristic of what RBIS or at a minimum to encouraging faculty members to report exactly what they are doing when they say they are using Collaborative Learning.

Cooperative Learning

Cooperative Learning can be defined as a structured form of group work where students pursue common goals while being assessed individually (Millis & Cottell, 1998; Michael Prince, 2004). Hsiung divided a planar dynamics course into two sections: Cooperative Learning and individualistic learning. Over time, there was increased performance with the cooperative learning group on both homework and tests (2012).

Cooperative Learning demonstrated moderate to high fidelity with just over half (54%) of cooperative learning users using all three required components and (43%) using two out of the three (Table 3). As can be seen in Table 9, having students "work on problems sets or projects in pairs or small groups" and "discuss a problem in pairs and groups" are used by 100% of Cooperative Learning users. There was a significant difference between users and non-users having students spend class time "work[ing] on problem sets or projects in pairs or small groups" and having students "participate in group work for which the assessments are designed so that individuals can earn different scores for their work on the assignment" (Table 9). Though there was no significant difference between users and non-users for having students "discuss a problem in pairs or groups" (Table 9), again, 100% of the users spent time on this activity. However, this activity is associated with six other RBIS and is therefore also used by 87% of Cooperative Learning non-users.

There was also a significant difference between users and non-users when having students spend class time to “report their group’s findings to the entire class (formally or informally)” (Table 9). However, there was not a significant difference with the rest of the indicative activities. There was a fairly high (77% - 92%) percentage of users who spent time with the activities.

Table 9: Cooperative Learning Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 26) and spent time on activity	Faculty who **don't** use RBIS (n = 140), but spent time on activity	p-value
Participate in group work for which the assessments are designed so that individuals can earn different scores for their work on the assignment	Required	54%	23%	0.001*
Work on problem sets or projects in pairs or small groups	Required	100%	77%	.005* [1]
Discuss a problem in pairs or groups	Required	100%	87%	0.079 [1]
Report their group's findings to the entire class (formally or informally)	Indicative	88%	31%	<0.001* [1]
Complete specifically designed activities to "learn" course concepts on their own without being explicitly told	Indicative	77%	53%	0.023
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	92%	72%	0.027 [1]
Provide the answer(s) to a posed problem or question before the class can proceed	Indicative	85%	82%	1.00 [1]

* indicates a significant relationship with alpha = 0.01
[1] indicates Fisher's Exact Test used

An unexpected significant relationships was found between Cooperative Learning and having students “work on problems or projects that require students to seek out new information not previously covered in class” (p <0.001) with 77% of Cooperative Learning users also spending time on this activity as compared to 38% of non-users; this relationship may reflect the Complexity of the projects/problems that faculty members have students work on cooperatively.

However, further investigation is needed to fully evaluate the relationship between Cooperative Learning and this activity.

Problem Based Learning (PBL)

Problem-Based Learning (PBL) centers on an open-ended, authentic problem that requires students to identify objectives and needs to find a solution for the problem. In this environment, the instructors take on the role of facilitator rather than source of information while students work in self-directed teams (Michael Prince & Felder, 2006). Reeves and Laffey used PBL in an Introduction to Engineering course and found an increase in the students' problem solving skills (1999).

Problem-Based Learning had a fairly high level of fidelity with 65% (Table 3) of users spending time on all five required critical components. Additionally, three of the five components discriminated between users and non-users (Table 10). That is, I found a statistically significant difference between PBL users and non-users for three of the five critical components. The required component, "discuss a problem in pairs or groups," that was not significant was used by 100% of the PBL users, but also used by a high percentage (86%) of non-users. This activity is mapped to several other RBIS so it is expected that non-PBL users would also spend time on this activity. Also, the required component "work on projects or situations from real engineering practice" was not significant with 92% of reported users also spending time on this activity as compared to 78% of non-users.

There was considerable fidelity among the indicative components for PBL as well, with over 70% of users also using two indicative components. The third component was used by a lower percentage of users, but looking at the indicative components, two of the components ask about assessing the student work in groups (receiving one grade per group or individual grades). Many faculty members may use just one of these components because they both focus on grading and it is not necessary to use both. It was also shown that a majority of PBL users (71%) give one grade per group rather than individual grades within the team (42%). A significant difference was also found between PBL users and non-users for assigning one group-grade for work completed as a group.

A significant difference was also found between PBL users and non-users with respect to spending time having students "report their group's findings to the entire class (formally or informally)" ($p < 0.001$) with 66% of users also spending time on this activity as compared to 32% of non-users. This may imply that instructors, as part of Problem-Based Learning, have their students report their findings to the class in the form of formal presentations at the end of the semester. Further investigation will be needed to explore the nature of this relationship.

Table 10: Problem Based Learning Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 38) and spent time on activity	Faculty who **don't** use RBIS (n = 128), but spent time on activity	p-value
Complete specially designed activities to "learn" course concepts on their own without being explicitly told	Required	84%	48%	<0.001*
Work on problems or projects that require students to seek out new information not previously covered in class	Required	82%	46%	<0.001*
Work on problem sets or projects in pairs or small groups	Required	97%	76%	0.002* [1]
Discuss a problem in pairs or groups	Required	100%	86%	0.014 [1]
Work on projects inspired by problems or situations from real engineering practice.	Required	92%	78%	0.059 [1]
Participate in group work for which they earn the same score as every other member of the group	Indicative	71%	36%	<0.001*
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	89%	71%	0.020 [1]
Participate in group work for which assessments are designed so that individuals may earn different scores for their work on the assignments	Indicative	42%	23%	0.024

* indicates a significant relationship with alpha = 0.01

[1] indicates Fisher's Exact Test used

Think-Pair-Share

Think-Pair-Share is a quick active learning strategy where the instructor poses a problem, has students work on it individually for a short time, and then has them form pairs and reconcile their solutions before calling on them to share their responses. (Felder & Brent, 2009) Byerley used multiple active learning techniques in a thermodynamics course, including Think-Pair-Share, and found an increase in students engagement and project performance (2001).

Think-Pair-Share has a moderate-high fidelity with 62% of users using all 3 critical components and 100% using more than 2 (Table 3). When looking at the percentage of faculty members who also spend time on the critical components, it can be seen that nearly all (95-100%) of Think-Pair-Share users ensure students “discuss a problem in pairs or groups” (significantly higher than non-users) and “provide answer(s) to a posed problem or question before the class session can proceed” (Table 11). A significant difference was also found between users (67%) and non-users (31%) of Think-Pair-Share spending time having students “report their group’s findings to the entire class (formally or informally)” (Table 11). Also, a significant difference was found between Think-Pair-Share users and non-users with respect to spending time on the general active learning activity. This relationship could be based on the general discussion of Think-Pair-Share under the heading of a way to complete active learning and therefore, faculty members make the connection that they spend time on this activity.

Table 11: Think-Pair-Share Required and Indicative Components

	Required/ Indicative	Faculty who use RBIS (n = 39) and spent time on activity	Faculty who **don't** use RBIS (n = 127), but spent time on activity	p-value
Report their group's findings to the entire class (formally or informally)	Required	67%	31%	<0.001*
Discuss a problem in pairs or groups	Required	100%	86%	0.008* [1]
Provide answer(s) to a posed problem or question before the class session can proceed	Required	95%	79%	0.028
Participate in activities that engage them with course content through reflection and /or interaction with their peers	Indicative	95%	69%	0.001* [1]

* indicates a significant relationship with alpha = 0.01

[1] indicates Fisher's Exact Test used

Think-Pair-Share was also found to have significant relationships between five additional activities. These activities were not predicted to have a significant relationship with Think-Pair-Share based on the literature. First, Think-Pair-Share was found to have a significant relationship with having students “work on projects inspired by problems or situations from real engineering practice” (p = 0.002 using Fischer’s Exact Test) with 97% of users spending time on the activity compared to 76% of non-users. This may indicate that faculty members use “real-world” problems as the basis for Think-Pair-Share activities. Further research will be needed to investigate this relationship.

Another unexpected relationship was found between Think-Pair-Share and having students “work on problem sets or projects in pairs or small groups” ($p < 0.001$ using Fischer’s Exact Test) with 100% of Think-Pair-Share users spending time on this activity as compared to 75% of non-users. Traditionally, Think-Pair-Share is discussed with respect to discussing a conceptual question with a partner (Felder & Brent, 2009). However, from this result, it seems that engineering faculty members may have adapted this RBIS to include working problems as a pair and reporting their findings back to the class. Many of the interview participants discussed having students work on a problem individually, with a group, then showing their work on the board as an implementation of Think-Pair-Share. With such a high percentage of users also spending time on this activity, more in-depth analysis is needed to figure out how faculty members are using Think-Pair-Share and whether this activity should be included as a potential critical component.

Another activity with a significant difference between Think-Pair-Share users and non-users was “Use means other than clickers to 'vote' on the correct answer of a multiple choice question” (p-value = 0.009) with 62% of users also spending time on the activity as compared to 38% of non-users. Faculty may be using this activity as a way for students to “share” their answers with the class but further investigation is needed around this relationship.

Having students "participate in group work for which they earn the same score as every other member of the group" was also unexpectedly found to have significant differences between users and non-users (p-value = 0.001) with 67% of users also spending time on the activity as compared to 37% of non-users. This may be related to having students submit their "pair" work for a grade; this is not how Think-Pair-Share is traditionally discussed in the literature (Byerley, 2001; Felder & Brent, 2009), so further analysis will need to be completed to investigate this relationship.

The final unexpected significant difference was between Think-Pair-Share and having students "work on problems or projects that require students to seek out new information not previously covered in class" (p = 0.004) with 74% of Think-Pair-Share users also spending time on this activity as compared to 48% of non-users. Again, this is not an activity generally associated with Think-Pair-Share and will need further investigation to understand the relationship.

One reason for Think-Pair-Share showing a relationship with so many activities not traditionally discussed with Think-Pair-Share may indicate that these users also use other RBIS associated with the activities such as Cooperative Learning, Collaborative Learning, or Problem Based Learning. Further research into how Think-Pair-Share is used in the classroom is needed to further understand the large number of unexpected relationships.

Discussion and Conclusion

Overall, these results show a promising level of fidelity amongst Statics instructors. Due to the high number of non-users that were using some of the critical components, the foundation was set for a new investigation exploring instructors who are using the critical components of an

RBIS without labeling it as an RBIS. This raises new research questions such as “What is the importance of labeling an RBIS?” This research study seeks to help establish the critical components of RBIS to aid not only in developing a common language among researchers, but also to help present RBIS to practitioners in a way that is easy for them to translate into the classroom, i.e. a list of classroom activities. The next steps for creating this common language will be to ensure consistent labeling within the research community by discussing through conferences and journal articles the importance of being consistent, potentially by using Fidelity of Implementation as framework. The conversation could then move to faculty development efforts and the conversations with practitioners about the research.

There is also a distinction between simple and more complex RBIS. The more simple RBIS with one required critical component had higher levels of fidelity and fewer unexpected results with other activities. More complex RBIS had slightly lower levels of fidelity and a larger number of unexpected relationships with other activities. There was also confusion with some of the more complex RBIS, such as with distinguishing Cooperative Learning from Collaborative Learning. These had many overlapping critical components and many unexpected overlapping results. In the interviews, multiple participants expressed that they felt these RBIS were very similar and questioned what the differences were.

Fidelity of Implementation is an important lens for investigating innovative, research-based instructional strategies implemented in engineering education. Overall, this study has shown a promising level of fidelity among engineering sciences faculty members. Most of the faculty members that identified as users of a specific RBIS also indicated that they use at least one of the corresponding activities identified by the literature as necessary for implementing that RBIS. It should be noted that RBIS with one required critical component (such as concept tests) had higher levels of overall fidelity when compared to the more complex RBIS.

Encouraging progress was also made in identifying the critical components that distinguish RBIS users from non-users. Many critical components where used significantly more by users of certain RBIS when compared to non-users. However, a number of the components did not show a difference, indicating that the critical component was not an independent indicator of certain RBIS or that it did not show a relationship with the RBIS. Additionally, some activities that were not intended to differentiate between users and non-users did present a significant difference. Further research is needed to investigate these relationships.

Future Directions for Research

Fidelity of Implementation is a fairly unexplored area within engineering education and more research is needed. The future research needed in this area falls into a number of different categories.

First, further research should be done to establish the critical components of commonly used RBIS. While this study began this process, further investigation is needed. Direct measures, such as classroom observations of RBIS use, will help explore the unexpected relationships found throughout this study and further develop the critical components of each RBIS.

Another direction for future research should be integrating fidelity into the development of new instructional strategies. Developing the critical components alongside the strategy will help the initial dissemination of the strategy and will help to avoid confusion between the new strategies and previously developed ones.

Yet another direction for future research is to explore the reasons for varying levels of fidelity. To better understand and improve fidelity, it is important to understand the factors that influence it. What characteristics of the instructor, RBIS, or developer impact fidelity? Which factors are most influential? One example of a future study would be comparison list of critical components identified by developers and faculty users. Finding the similarities and differences between these two groups could offer insight into why there are varying levels of fidelity.

Implications for Practice

Fidelity of Implementation has many implications for teaching and learning in undergraduate engineering. First, fidelity helps to ensure researchers and practitioners are using the same language. High fidelity ensures that when someone indicates use of concept tests, their audience knows what activities are being implemented in association with concept tests.

Also, a focus on Fidelity of Implementation offers a more explicit description of how to use each RBIS because it is broken into critical components. Using fidelity as a framework for faculty development offers opportunities to ensure it is made clear what the expectations for each RBIS are and the ways to integrate the critical components into the classroom.

Another implication for this work is that it draws attention to the issue that when faculty members use an RBIS with unacceptable levels of fidelity the benefits of RBIS may be compromised, potentially hindering student learning.

Also, as a note to researchers developing new RBIS, faculty members are more likely to implement RBIS with full fidelity if there are only a few required critical components. Keeping new RBIS simple may help them be adopted in the classroom.

Examining and reporting on the Fidelity of Implementation is also not limited to the RBIS discussion. For many other research-to-practice settings, such as extra-curricular activities or assessment programs, reporting on the critical components that are required for the program to be effective is very important. Thus, Fidelity of Implementation has broad potential across engineering education research and practice.

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Chapter 5

Conclusion

The overall goal of engineering education is to improve student learning in engineering. By understanding the gap between research and practice, the engineering education community as a whole can make strides to bring developed innovative practices from the research to the classroom where it can be directly implemented to improve student learning. Only examining one side of the research-practice gap will not improve student learning; therefore, this study brought the practitioner's perspective to the researchers while examining the implementation of research in the classroom. These three manuscripts tell one complete story about the implementation of educational research into Statics practice. An overview of the results for each research question can be found in Table 1. These findings can aid both researchers and practitioners in improving student learning and engagement (the mutual goal of both research and practice).

Table 1: Overview of Research Questions and Findings

MS	Research Questions	Findings
MS 1	RQ 1a: What common practices (activities) are being used in the Statics classroom? RQ 1b: What unique characteristics of Statics influence these practices?	RQ 1a: Lecturing, Instructor working Examples, Having student work problems (individually and in groups), and many more RQ 1b: Statics content, place in curriculum, problem solving like an engineer
MS 2	RQ 2: What barriers do faculty members perceive to the adoption of RBIS?	RQ 2: Each of Rogers' characteristics presented potential barriers. Complexity was the largest barrier pointing to time, class size, and characteristics of specific RBIS
MS 3	RQ 3a: With what degree of fidelity are RBIS being implemented within the Statics classroom? RQ3b: Do the critical components that characterize an RBIS discriminate between Statics faculty members who claimed to use the RBIS and those who do not?	RQ 3a: For RBIS with few Required Critical Components, there was a high number of instructors with complete fidelity. RQ 3b: Using Chi Square, some Critical Components discriminated between users and non-users. Some of the similarities between users and non-users resulted from a high number of non-users also spending time on the Critical Components

This dissertation presented three studies investigating the teaching practices of instructors in the Statics classroom. Instructors recognized the important role that Statics can play in the curriculum due to its placement at the beginning of student's academic careers and the fundamental content that the course covers. Additionally, many students are first exposed to the application of math and physics to solve a problem in this course, enhancing its importance. By establishing a foundation of current practices that instructors are currently implementing in the classroom, Manuscript 1, I found that Statics instructors are evolving their teaching practices to include a wider array of activities beyond lecturing; however, lecturing is still the most common activity occurring in the Statics classroom. Using examples and allowing students to work problems both individually and in pairs or groups are also common to many Statics classrooms.

As the investigation continued in Manuscript 2, the primary research focus shifted from current practices to whether or not specific Research-Based Instructional Strategies (RBIS) were being used in Statics. This investigation explored the barriers instructors face when deciding to adopt RBIS into their classrooms. Qualitative interviews revealed a majority of instructors indicated some awareness with RBIS, but a number of instructors had not tried RBIS or had discontinued use after trying an RBIS. A number of barriers were also revealed through the interviews. Each Diffusion of Innovation characteristic (Relative Advantage, Compatibility, Complexity, Trialability, and Observability (Rogers, 2003)) was found to present a barrier to RBIS adoption for at least one participant. Though the individual Statics instructors expressed varied opinions of the Relative Advantage of different RBIS groups, patterns emerged from the data. For example, many instructors felt RBIS were aligned with enhancing the process of learning, but generally one RBIS group was believed to be incompatible. Trialability and Complexity were marked as significant barriers to implementation, with many instructors citing time constraints, class size, and characteristics of the different RBIS groups in their reasoning. Observability was the most broadly discussed barrier. Instructors did not generally associate the barriers with a specific

RBIS group, but did cite a lack of data, knowledge of evaluation methods, and a uniform objective for RBIS as barriers to implementation. In addition to the DOI characteristics, university support was often discussed as neither a support nor a barrier for RBIS use. However, Centers for Teaching and Learning were cited by a number of faculty members as a positive influence on using RBIS in their classrooms. Also, the idea of instructor inertia developed from the interviews indicating that one of the biggest barriers to instructors not using RBIS is that they have not used them in the past and have no desire to change their teaching practices.

Finally in Manuscript 3, the investigation transitioned to a quantitative exploration of the level of adherence instructors pay to the originally developed RBIS when implemented in the classroom. I found that Fidelity of Implementation can serve as an important lens for investigating innovative practices, such as RBIS, being implemented within engineering education. Overall, this study showed a promising level of fidelity among Statics faculty members. Most of the faculty members identified as users of a specific RBIS from their survey responses also indicated that their use of at least one of the corresponding activities identified by the literature as necessary for implementing that specific RBIS. It should be noted that RBIS with one required critical component (such as concept tests) had higher levels of overall fidelity when compared to the more complex RBIS. Additionally, methods were developed to identify RBIS users from non-users. Many critical components were used significantly more by users of RBIS when compared to non-users. However, a number of the components did not result in a significant difference indicating that the critical component was not an independent indicator of an RBIS or that it did not show a relationship. Additionally, some activities that were not intended to differentiate between users and non-users did present a significant difference indicating a relationship between using that RBIS and that activity; for example, Think-Pair-Share was found to have a significant relationship with having students “work on projects inspired by problems or situations from real engineering practice.” Further research is needed to investigate these relationships and strengthen the identification method.

Generalizability of Results

Where the unique attributes of Statics as a course have been discussed, there are still a number of attributes that are shared with other courses that aid in the potential generalizability of these results. First, Statics is an engineering sciences course as are a number of other courses such as thermodynamics and electrical circuits. These engineering sciences courses share a number of common attributes such as being early in the curriculum and being the first time engineering students are asked to apply mathematics and science principles. These attributes were also characterize by the instructors in this study as unique to Statics, but are also common to other engineering sciences courses within other engineering disciplines. Due to these similarities, the results from this dissertation can be generalized to other engineering sciences courses; especially those found in Manuscript 1.

Additionally, Manuscript 2 and Manuscript 3 were contextualized within the Statics classroom; however, the focus was more directed on the Research-Based Instructional Strategies (RBIS) rather than the contextual nature of the class. While Statics is an important element of how the instructors viewed and used specific RBIS, they were also expanding on their views of all RBIS; leading to a more generalizable discussion of the barrier to adopting RBIS and the Fidelity of Implementation of RBIS.

The generalizability of these results should be investigated in future work to explore the adoption of RBIS within more advanced courses and within other disciplines, both within and outside of engineering.

Contribution to Evolution of Diffusion of Innovation Theory

While analyzing the results of this study, there were challenges to working with the Diffusion of Innovation framework while not targeting a new physical technology. DOI has been used repeatedly for educational and other innovative practices; however, when the instructors were discussing the DOI characteristics, Trialability and Observability were more challenging to directly apply to the classroom. Trialability was difficult for the instructors to evaluate because it was not a piece of technology that could be tested in a store before purchasing. In order to try these RBIS, instructors must dedicate time to prepare each RBIS for implementation in *their* classroom; this requires more commitment than with a traditional technology-based innovation. However, though it requires more time, many instructors indicated that it would be feasible to try an RBIS once, which could potentially be an avenue for increasing adoption. By offering instructors an opportunity to just “try” an RBIS one time with the support of the RBIS developer(s) or the Center for Teaching and Learning at their university, instructors may potentially overcome their initial trepidation of using and RBIS, which could help them using them more regularly in the classroom.

In addition to Trialability, Observability is more challenging with an RBIS than with traditional technological innovations: it is harder to see the benefits of using an RBIS right away. It is not like a cell phone for which many people can see the benefits of being able to make a phone call at nearly any location; in the case of an emergency or car trouble, the phone user can call for help. Observations such as this are more tangible when encouraging technology to be adopted and not always available when trying to encourage innovative teaching practices. When discussing Observability, the barriers that emerged were lack of "data," lack of knowledge of assessment methods, and a non-uniform RBIS objective. These barriers can be viewed as interrelated as instructors have trouble collecting data because they are unsure about the appropriate methods to use. One of the reasons they are not sure about the methods to use is because they have varied views with regards to the objective of RBIS. Knowledge of assessment techniques is a serious barrier to adoption, but is potentially fixable through faculty development and the aid of the educational research community. For example, researchers could aid instructors by discussing the objectives they see as achievable through RBIS use when working towards implementation. Also, including training for simple evaluation methods for instructors could reduce barriers and increase adoption. A final recommendation would be to give potential adopters access to previous data on the effectiveness of an RBIS for them to evaluate the success of an RBIS for themselves.

Complexity was noted in the results as the DOI characteristic that is most commonly noted as a barrier to implementation. Where the Complexity of an innovation can increase the difficulty of implementing an RBIS, it is a very easy decoy for instructors to focus on and cite as a barrier to implementation. The real reasons for not adopting an RBIS may be more implicit beliefs about teaching and learning that would align more with Relative Advantage or Compatibility than Complexity; this became more apparent when participants would reference Complexity barriers, such as time and class size, when discussing all of the other characteristics. In addition, a number of faculty members felt RBIS they were using were less complex; showing that since they saw the advantage or found the RBIS compatible with their views on learning, the barriers of implementation were overcome with limited Complexity. A future study should more explicitly explore the teaching beliefs of instructors and the advantages instructors see to using not only RBIS, but also their teaching style in general, without the red herring of Complexity to further the investigation into the barriers to RBIS implementation.

Contribution of Overall Dissertation

The results yielding from this dissertation were not overly surprising for those familiar with engineering education research or practice; however, they are original. There has not been a previous study of the current teaching practices in Statics, or many other engineering courses. This type of study is important. How can researchers hope to change practices when the current practice is unknown? By providing researchers and practitioners with a common set of activities used by multiple current Statics instructors, both communities may make attempts to collectively improve students' educational experiences in the Statics classroom. This study allowed practitioners to see the classroom practices of other instructors, which may influence activities they implement in their classroom. These practices may seem less outrageous coming from another practitioner rather than from researchers who may be seen as not understanding the practical aspects of teaching in the Static classroom. Through these results, researchers can better relate their research to practitioners and potentially develop innovations for the classroom using current practices. This may improve adoption and encourage adoption of multiple teaching practices. Connecting research and practice is important because both are aiming to improve student learning and, by working together, they can more quickly and effectively achieve this goal.

Again, those familiar with engineering education will not find it surprising that instructors see a number of barriers to using RBIS in their classrooms. However, there have not been many previous studies targeting the barriers engineering instructors face when using Research-Based Instructional Strategies. Adopting new technology into education has been previously studied, but not in this context. There are a limited number of other studies that place the research and theory in the hands of the practitioners. The practitioners' views on these RBIS may greatly aid researchers in improving adoption of their discoveries. This study allowed the practitioners meant to use these RBIS to voice their concerns, so researchers can address the concerns and aid researchers and practitioners to work together to improve student learning.

The Fidelity of Implementation (FOI) component of this dissertation is unique. FOI has not been previously examined in engineering education. This is an important component to connecting research and practice because, not only can elements be lost or changed when practitioners adapt a researcher's work for implementation, but they can also be lost when reporting new practices back to the academic community when lost or changed elements are not discussed. FOI is an important component in increasing conversational transparency between research and practice. It gives practitioners the ability to communicate adaptations to an RBIS in order to progress the conversation between researchers and practitioners. This discussion may then include the impacts of RBIS allowing changes to the student experience. FOI also assists researchers by allowing them to establish critical components that list specific activities to be completed in the classroom, which enables practitioners to identify the necessary steps to implement an RBIS. Fidelity of Implementation is an important element that needs to be included in the RBIS conversation.

Overall, the contribution of this dissertation was presenting a start to finish characterization of the adoption process. Where other studies have investigated different elements of the adoption process, this dissertation took a systematic approach starting with an assessment of current practices, then investigating the adoption practices for instructors and the barriers they face, and finally, evaluating the entire process through Fidelity of Implementation. This systematic approach is a new way of exploring change in the classroom that can offer new perspectives and approaches that may aid in accelerating the adoption process.

Future Work from Overall Dissertation

In addition to the intellectual contributions of this dissertation work, the new method of using the table activity during the interviews was a more powerful than anticipated. Initially, the table activity was meant as a conversation starter; however, it allowed the analysis to directly address the components of the theory to gain a new perspective on both the existing theory and RBIS. Therefore, an additional area for future work should focus on the usability of the table activity as a methodological tool to directly connect research and practice to gain the practitioner perspective on the research. Another element of future work, made apparent through the use of the table activity, could investigate the comparison between practitioner views and those helped by the developers and researchers of RBIS. These different views could reveal more information about the gap between the researcher and practitioner perspectives.

Future work should also include an investigation into the variety of instructors who teach Statics. The current study revealed that participants came from a variety of backgrounds and taught the same class in a variety of ways. It would be interesting to specifically investigate the influence of these varied backgrounds on instructors' teaching beliefs and practices. This would be an innovative way of exploring this research area by not just investigating how beliefs influence teaching, but how past experience influence instructor beliefs. Some of the instructors had never taken Statics as a student, how does that influence/change how they teach? Some instructors relied heavily on their industry background; therefore, how does that influence/change their teaching practices? A future study should investigate the impact of these different teaching approaches on student learning.

Another area of future research would be to explore the importance of labeling practices as RBIS. If an instructor is spending time on all of the critical components required of an RBIS, however, not labeling it as an RBIS, how does that influence research and the practice? What are the implications of this for research and practice? In practice, the labels may not carry as much weight as with researchers who are trying to help practitioners and track RBIS implementation.

Yet another important element for future work from this dissertation is to include more direct measures, such as classroom observations. One of the limitations of this work is the self-report nature of both the survey and the interviews. Classroom observations could help triangulate and validate the results found here.

Summary

The overall goal of this dissertation, as it is now done, was to investigate the adoption of new practices, specifically Research-Based Instructional Strategies (RBIS), by US and Virginia Statics instructors. Each of the individual studies in this dissertation was a step in exploring this phenomenon. First, before changes to new practices can be examined, current practices must be established. For most research, this is done through literature reviews of published results from research studies. However, this dissertation explored Statics instructors and their teaching practices within the classroom, which are not regularly evaluated. Therefore, the first step in this dissertation evaluated the changes happening in the Statics classroom, as discussed by the instructors teaching this course, to explore common teaching practices (Manuscript 1). The next step was a more direct assessment of the adoption of RBIS. First, instructor familiarity with RBIS was examined, which helped to understand if RBIS had already been implemented in the classroom. However, knowing that RBIS are or are not being used is helpful, but does not offer any directions for future work and does not aid in understanding instructor motivations about adoption. Therefore, instructors were also asked to discuss the characteristics of each RBIS that presented barriers to adoption (Manuscript 2). The final step in this dissertation was to evaluate the adoption process. When adopting an RBIS, adapting some of the elements to fit within the context of the specific university/classroom can be helpful. However, these changes are not generally discussed or evaluated with respect to the impact of these adaptations. Part of this is discovering how many changes an instructor can make to RBIS before they are actually implementing something else with different (potentially negative) educational influences. Therefore, this dissertation sought to explore the application of a Fidelity of Implementation framework to RBIS and their implementation in the Statics classroom. Fidelity of implementation was developed in K-12 settings to evaluate how well innovations follow the original intent (O'Donnell, 2008) (Manuscript 3). This is an important element for evaluating the adoption of new practices. In summary, to fully investigate how RBIS were being adopted by Statics instructors, this dissertation assessed current practices, Statics instructor familiarity with

RBIS, the barriers instructors see to adopting, and, finally, explored the potential adaptation of implemented RBIS.

One of the goals of this research study was to aid in bridging the research to practice gap by identifying the practitioner's perspective of the research. From these perspectives, it is hoped that a dialogue can develop between researchers and practitioners that will help researchers disseminate their findings while helping practitioners overcome the barriers they face when attempting to implement new instructional strategies in the classroom. I hope this spurs important conversations to improve Statics teaching.

References for Chapter 5

O'Donnell, C. L. (2008). Defining, conceptualizing, and measuring fidelity of implementation and its relationship to outcomes in K-12 curriculum intervention research. *Review of Educational Research, 78*(1), 33-84. doi: 10.3102/0034654307313793

Rogers, E. M. (2003). *Diffusion of Innovations*. New York: The Free Press.

Appendix A: Survey

Research Based Instructional Strategies in Engineering Survey

Your responses to this survey regarding your instructional practices will help us to better understand how engineers are being educated. All data from this survey will remain confidential and your participation is entirely voluntary. Thank you for your participation in this important project.

Q1. When did you last teach engineering Statics or a similar course?

○ last semester

○ last year

○ within the last 5 years

○ I have **not** taught Statics within the last 5 years

IF Q1=I have not…, GO TO END

Section 2. This section addresses your general beliefs about learning Statics. Please indicate the degree to which to agree or disagree with each of the following statements.

		Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a.	Lecturing is the best use of limited Statics class time.	1	2	3	4	5
b.	Students learn Statics better when an instructor or teaching assistant is available while they are working on problems.	1	2	3	4	5
c.	The most effective learning in Statics happens when students listen to a well-prepared lecture.	1	2	3	4	5
d.	The most effective learning in Statics happens when students solve problems.	1	2	3	4	5
e.	A formal lecture is necessary before students can effectively solve Statics problems.	1	2	3	4	5
f.	Students learn Statics better when they work on problems together than when they work on problems alone.	1	2	3	4	5
g.	When students talk to each other during Statics class, it distracts them from learning.	1	2	3	4	5

Section 3. This section addresses the Statics course you've taught most recently. Please indicate what percentage of time on average your students spent/spend on each of the activities below during class time.

		Never 0%	Rarely 1-25%	Sometimes 26-50%	Often 51-75%	Nearly Every Class 76-100%
1.	Watch, listen and/or take notes on a lecture.	1	2	3	4	5
2.	Discuss a problem in pairs or groups.	1	2	3	4	5
3.	Answer multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions.	1	2	3	4	5
4.	Spent time discussing pre-class assignments which helped you re-evaluate student learning and adjust your lecture "just in time."	1	2	3	4	5
5.	Work on projects inspired by problems or situations from real engineering practice.	1	2	3	4	5
6.	Provide the answer(s) to a posed problem or question before the class session can proceed.	1	2	3	4	5
7.	Work on problem sets or projects in pairs or small groups.	1	2	3	4	5
8.	Use clickers to "vote" on the correct answer of a multiple choice question.	1	2	3	4	5
9.	Use means other than clickers to "vote" on the correct answer of a multiple choice question.	1	2	3	4	5
10	Complete specially designed activities to "learn" course concepts on their own without being explicitly told.	1	2	3	4	5
11	Participate in group work for which they earn the same score as every other member of the group.	1	2	3	4	5
12	Participate in group work for which the assessments are designed so that individuals may earn different scores for their work on the assignment.	1	2	3	4	5
13	Report their group's findings to the entire class (formally or informally).	1	2	3	4	5
14	Work on problems or projects that require students to seek out new information not previously covered in class.	1	2	3	4	5
15	Watch lectures online so that class time can be used for other activities	1	2	3	4	5
16	Participate in activities that engage them with course content through reflection and/or interaction with their peers (other than watching, listening and/or taking notes).	1	2	3	4	5

Section 4. This section addresses research based instructional strategies you may have used in any Statics courses you've taught recently. Please indicate your level of use and knowledge of each strategy below.

		I Currently Use It	**I Have Used it in the Past**	**I Have Used Something Like it But Did Not Know Name**	**I am Familiar with It, But Have Never Used It**	**I Have Heard Name, But Know Little Else About It**	**I Have Never Heard of It**
		----------------Please Click One Response Option--------------					
1.	**Active Learning**. A very general term describing anything course-related that all students in a class session are called upon to do other than passively watch, listen and take notes.	1	2	3	4	5	6
	IF Q4a>1, GO TO Q4c						
a.	Please describe the active learning methods you use(d) in your class(es).	____________					
2.	**Just-In-Time Teaching**. Asking students to individually complete homework assignments a before class, reading through their answers before class and adjusting the plan for the class accordingly.	1	2	3	4	5	6
3.	**Think-Pair-Share**. Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions. After that, calling on students to share their responses.	1	2	3	4	5	6
4.	**Concept Tests**. Asking multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions.	1	2	3	4	5	6
5.	**Peer Instruction**. The instructor poses a conceptual question in class, asks students to respond individually (possibly using a classroom response system or "clickers"), and then shares the distribution of responses with the class. Students form pairs, discuss their answers, and then vote again.	1	2	3	4	5	6
6.	**Collaborative Learning**. Asking students to work on a common task in small groups.	1	2	3	4	5	6
7.	**Cooperative Learning**. A structured form of group work in which faculty help students develop team skills, assess both individual learning as well as overall group results, and structure assignments to strengthen interactions between team members.	1	2	3	4	5	6

		I Currently Use It	I Have Used it in the Past	I Have Used Something Like it But Did Not Know Name	I am Familiar with It, But Have Never Used It	I Have Heard Name, But Know Little Else About It	I Have Never Heard of It
8.	**Inquiry Learning.** Presenting students with questions, problems or a set of observations and using this to drive the desired learning.	1	2	3	4	5	6
9.	**Problem-Based Learning**. Acting primarily as a facilitator and placing students in self-directed teams to solve open-ended problems that require significant learning of new course material.	1	2	3	4	5	6
10	**Statics Concept Inventory**. Assessing students' mastery of conceptual ideas in Statics using this multiple choice test.	1	2	3	4	5	6

[Question Q4aa.1... Asked After Each Q4a, Q4b, Q4d-Q4m if Q<4]. How long have/did you use(d) this teaching strategy? (Please click one response option)

○ Less than one semester or term
○ One complete semester or term
○ More than one complete semester or term

[Question Q4aa.2... Asked After Each Q4a, Q4b, Q4d-Q4m if Q<6]. How did you first hear about this teaching strategy? (Please click one response option)

○ Read article or book about it
○ Presentation or workshop at my professional society conference (e.g., ASME)
○ Presentation or workshop at another type of conference (e.g., ASEE)
○ Presentation or workshop on my campus
○ In-depth workshop of one or more days (e.g., NETI, NSF-sponsored)
○ Colleague (word of mouth)
○ Do not recall
○ Other (please specify how you first heard about the teaching strategy): _______________________________)

[Question Q4aa.3... Asked After Each Q4a, Q4b, Q4d-Q4m if Q<6]. Please indicate the methods below that you may have used to learn more about this teaching strategy. (Please click on all response options that apply)

○ Read article or book about it
○ Presentation or workshop at my professional society conference (e.g., ASME)
○ Presentation or workshop at another type of conference (e.g., ASEE)

○ Presentation or workshop on my campus

○ Workshop at another location (e.g., NETI, NSF-sponsored)

○ Colleague (word of mouth)

○ Do not recall

○ Other (please specify how you learned more about the teaching strategy: ______________________________)

[Question Q4aa.4... Asked After Each Q4a, Q4b, Q4d-Q4m if Q<6]. Please click on any of the factors below that seriously discourage any potential plans for using this particular teaching strategy in the future. (Please click on all response options that apply)

○ Lack of evidence to support the efficacy of this instructional strategy

○ Too much advanced preparation time required

○ Takes up too much class time to let me cover the syllabus

○ Students would not react positively

○ My department and administration would not value it

○ My department does not have the resources to support implementation. Please explain: ______

○ Other: _______

Q5. Please comment on any factors that might prevent you from using more of the instructional strategies addressed in this survey in the future.

____

____

Q6. On average, approximately how many students were in the class section(s) the last time you taught Statics? ____

Q7. How often did you talk to or correspond with your colleagues or other Statics professors about teaching over the past two years? (Please click one response option)

○ Never

○ Once or twice per semester or term

○ Several times per semester or term

○ Weekly

○ Nearly every day

Q8. Approximately how many talks or workshops on teaching methods or other engineering education topics have you attended in the past two years (at professional meetings, on campus, or at other venues)? (Please click one response option)

○ None

- ○ 1-3
- ○ 4-9
- ○ 10 or more

Q9. What is your current rank? (Please click one response option)

- ○ Lecturer
- ○ Assistant Professor
- ○ Associate Professor
- ○ Full Professor
- ○ Other (Please specify your rank: ______________________________)

Q10. What is your gender? (Please click one response option)

- ○ Female
- ○ Male

Q11. In which department or program is your faculty appointment? (Please click one response option)

- ○ Mechanical engineering
- ○ Aerospace /aeronautical engineering
- ○ Engineering mechanics or equivalent
- ○ Civil engineering
- ○Other: ____

END. Thank you for your help with our study. Please click "submit" to end the survey.

Appendix B: Interview Protocol

Hello! I'm a graduate student in Virginia Tech's Engineering Education department and would like to talk to you as part of my dissertation research investigating how faculty make decisions about how to teach, specifically in the Statics classroom.

1. To begin, could you please walk me through a typical day in your Statics class.
    a. If I was sitting in on you class, what would I see the students doing?
    b. What would you be doing?
2. How long have you been teaching?
    a. How long have you been teaching Statics?
    b. How has your teaching changed over the years?
3. How, if at all, is Statics different from other classes you have taught?
4. How often do you talk to your teaching colleagues?
    a. What do you talk about?
5. In what ways is innovative teaching supported by your department and college?
6. Have you heard of the Statics Concept Inventory?
    a. *If yes,* Have you ever used it in your teaching?
        i. *If yes,* How have you used it?
    b. *If no,* The Statics Concept Inventory is a set of multiple choice questions utilizing common misconceptions as wrong answers. Would you be interested in using something that in your classroom?
        i. *If yes,* How do you think you might use it?
7. What was Statics like when you were an undergrad?
    a. How do you think your experience has impacted your teaching of Statics?
8. I'm going to give you a table now with a list of Research Based Instructional Strategies. There are a number of other items on the table, but for now we're going to focus on the first two columns. Are you using any of these RBIS in your classroom?
    a. Are there any you haven't heard of?
    b. Why did you decide to use that particular RBIS?
        i. How did you start using it?
9. Do your colleagues use many of these RBIS?

a. Why do you think that is?

10. Now, I'm going to ask you to fill out this table and rate a few of the RBIS with respect to 5 characteristics. The characteristics are listed in the first row, but I'm going to go through them to make sure we're on the same page.

The Relative Advantage: The perceived benefits of an innovation over the status quo.
The Compatibility: The consistency of the innovation with the adopter's values and past experiences.
The Complexity: The perceived difficulty of implementing the innovation.
The Trialability: The perceived ease of trying the innovation before adoption.
The Observability: The perceived ease of seeing the results of an innovation.

For the different RBIS, please mark if the characteristic is a benefit (check mark), challenge ("X" mark), or doesn't influence the RBIS (mark with a "0"). Please verbally walk me through what you're thinking about while completing this activity. *(Completes activity with interviewer asking clarifying questions)*

11. Of these 5 characteristics, which one do you think is the biggest barrier to using an RBIS?
    a. Are there other characteristics not listed here that you think are bigger barriers? Why?

12. What else should I have asked you about that I didn't?

Please read through the list of Research Based Instructional Strategies and their descriptions. Please also read the characteristics in the first row. For the RBIS you have used, please mark if the characteristic is a benefit (check mark), challenge ("X" mark), or doesn't influence the RBIS (mark with a "0").

RBIS	**Brief Description**	**Relative Advantage:** the benefit of doing it over lecturing	**Compatibility**: Similarity to how you think learning occurs	**Complexity:** How hard it would be to use this	**Trialability**: How easily you could try it before using it	**Observability**: How easy it is to see the how well it is working
Active Learning	A very general term describing anything course-related that all students in a class session are called upon to do other than simply watching, listening and taking notes.					
Think-Pair-Share	Posing a problem or question, having students work on it individually for a short time and then forming pairs and reconciling their solutions. After that, calling on students to share their responses.					
Concept Tests	Asking multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions.					
Cooperative Learning	A structured form of group work where students pursue common goals while being assessed alone.					
Collaborative Learning	Asking students to work together in small groups toward a common goal.					
Problem-Based Learning (PBL)	Acting primarily as a facilitator and placing students in self-directed teams to solve open-ended problems that require significant learning of new course material.					
Just-In-Time Teaching	Asking students to individually complete homework assignments a few hours before class, reading through their answers before class and adjusting the lessons accordingly.					
Peer Instruction	A specific way of using concept tests in which the instructor poses the conceptual question in class and then shares the distribution of responses with the class (possibly using a classroom response system or "clickers"). Students form pairs, discuss their answers, and then vote again.					
Inquiry Learning	Introducing a lesson by presenting students with questions, problems or a set of observations and using this to drive the desired learning.					

Appendix C: Factor Analysis Results

Table A: Factor Analysis (Round 1) for Eigenvalues greater than 1

	Components							
	1	2	3	4	5	6	7	8
Q2_1			.732					
Q2_2						.747		
Q2_3			.842					
Q2_4								.777
Q2_5			.780					
Q2_6						.676		
Q2_7			.453		.589			
Q3_1			.628		-.309			
Q3_2	.532				-.322	.400		
Q3_3				.781				
Q3_4				.329			.661	
Q3_5	.572						.366	-.391
Q3_6	.343				-.403		.612	
Q3_7	.726							
Q3_8				.662				
Q3_9				.620				
Q3_10	.578							
Q3_11	.743							
Q3_12	.663							
Q3_13	.786							
Q3_14	.770							
Q3_15	.475			.507	.338			
Q3_16	.649							
Q4_1		.472			.586			
Q4_2		.566						
Q4_3					.614			
Q4_4		.484		-.486				
Q4_5		.376		-.402	.465			
Q4_6	-.458	.370			.477			
Q4_7	-.404	.676						
Q4_8		.761						
Q4_9	-.339	.691						
Q4_10		.646						

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 17 iterations.

Table B: Factor Analysis limiting the number of components to 6

	Component					
	1	2	3	4	5	6
Q2_1			.731			
Q2_2						.731
Q2_3			.837			
Q2_4						.560
Q2_5			.753			
Q2_6						.680
Q2_7			.440		.592	
Q3_1			.634		-.306	
Q3_2	.534				-.358	.359
Q3_3				.793		
Q3_4		-.311		.481		
Q3_5	.650					
Q3_6	.356				-.403	
Q3_7	.720					
Q3_8				.606		
Q3_9				.618		
Q3_10	.605					
Q3_11	.728					
Q3_12	.652					
Q3_13	.774					
Q3_14	.777					
Q3_15	.427			.525	.300	
Q3_16	.634				-.326	
Q4_1		.463			.580	
Q4_2		.582				
Q4_3					.626	
Q4_4		.522		-.461		
Q4_5		.378		-.339	.492	
Q4_6	-.412	.379			.450	
Q4_7	-.392	.661				
Q4_8		.728				
Q4_9	-.339	.682				
Q4_10		.682				

Appendix D: Complete list of Interview Codes. Italics indicate discussed in one of the manuscripts

Classroom Activities	*Lecturing*	
	Examples	*Real world' examples*
		Examples of how to solve a problem
	Emotional experiences	
	one-on-one time	
	Problems and Projects	*Hands-on experiences*
	Working in groups	
	Multiple choice questions	
	Quizzes	
	Asking students questions	*Helping to solve examples*
		Review
	Homework	
	Clickers	
	Attendance	
	Assessing prior knowledge	
	Handouts	
	Reflecting/Writing assignments	
	Visualizations	
	Technology	
	Discussion	
Unique characteristics of Statics	*Place in curriculum*	
	Content	
	Thinking like an Engineer	*Problem Solving*
Student Challenges	Math Skills	
Colleagues	Advice	Sharing Experiences
	Group Teaching	
	Administrative needs	
	Departmental culture	Lack of interaction
	Collaboration	
	Not alone/similar situations	
	Using RBIS	
	Doing things differently	
	Personal guidance	
Contextual Differences	Multiple disciplines in course	
	Statics + another course	
	Amount of Class Time	Contact hours
		Summer Session
	Student motivation	
	Class size	
	Unique to university context	

	RBIS use	
	Adjunt faculty member	
Implementation Influences	Class size	
	Instructor personality/style	
	University Support	*Center for Teaching and Learning*
		Teaching Assistants
		Colleagues
RBIS	Active Learning	Don't Use Active Learning
	Think-Pair-Share	Don't Use Think-Pair-Share
	Just-in-Time Teaching	Don't Use Just-in-Time Teaching
	Concept Tests	Don't Use Concept Tests
	Peer Instruction	Don't Use Peer Instruction
	Collaborative Learning	Don't Use Collaborative Learning
	Cooperative Learning	Don't Use Cooperative Learning
	Problem-Based Learning	Don't Use Problem-Based Learning
	Inquiry Learning	Don't Use Inquiry Learning
	Confusion over difference between Collaborative and Cooperative Learning	
	Didn't know the name of the RBIS	
	Heard of the RBIS, but is not using it	
	Fidelity of Implementation	
Table Activity	*"I do it" bias*	
	Relative Advantage	
	Compatibility	
	Complexity	
	Trialability	
	Observability	
	Not for use in Statics	
Textbook		
Statics content		
Implementation Process		
Teaching Evaluations		
Statics Concept Inventory		
Background Information on Instructor		

Appendix E: Complete listing of critical components by associated RBIS

Just-In-Time Teaching	Required	Spent time discussing pre-class assignments which helped you re-evaluate student learning and adjust your lecture "just in time"	[1-5]
Inquiry Learning	Required	Work on problems or projects that require students to seek out new information not previously covered in class	[2, 3, 6]
	Indicative	Complete specifically designed activities to "learn" course concepts on their own without being explicitly told	[2, 3, 6]
Peer Instruction	Required	Answer multiple choice conceptual questions with distracters that reflect common student misconceptions	[7-11]
	Required	Use clickers to 'vote' on the correct answer of a multiple choice question	[7, 10, 12]
	Required	Discuss a problem in pairs or groups	[7-11]
	Required	Provide answer(s) to a posed problem or question before the class session can proceed	[7, 9-11]
	Indicative	Use means other than clickers to 'vote' on the correct answer of a multiple choice conceptual question	[8, 10, 11]
	Indicative	Report their group's findings to the entire class	[10, 13]
Concept Tests	Required	Answer multiple-choice conceptual questions with distracters that reflect common student misconceptions	[9-11, 13-16]
	Indicative	Use means other than clickers to 'vote' on the correct answer of a multiple choice question	[10, 13, 14, 16]
	Indicative	Use clickers to "vote" on the correct answer of a multiple choice question	[10, 14, 16]
	Indicative	Provide the answer(s) to a posed problem or question before the class can proceed	[10, 13, 14]
	Indicative	Discuss a problem in pairs or groups	[10, 13, 14]
Think-Pair-Share	Required	Report their group's findings to the entire class (formally or informally)	[14, 17-19]
	Required	Discuss a problem in pairs or groups	[14, 17-20]
	Required	Provide answer(s) to a posed problem or question before the class session can proceed	[18-20]
Problem-Based Learning	Required	Complete specially designed activities to "learn" course concepts on their own without being explicitly told	[2, 3, 21-23]
	Required	Work on problems or projects that require students to seek out new information not previously covered in class	[2, 3, 21-23]
	Required	Work on problem sets or projects in pairs or small groups	[2, 3, 21-23]
	Required	Discuss a problem in pairs or groups	[2, 3, 21-23]
	Required	Work on projects inspired by problems or situations from real engineering practice	[2, 3, 21-24]
	Indicative	Participate in group work for which they earn the same score as every other member of the group	[24, 25]
	Indicative	Participate in group work for which assessments are designed so that individuals may earn different scores for their work on the assignments	[23-25]
Collaborative Learning	Required	Work on problem sets or projects in pairs or small groups	[26-28]
	Required	Participate in group work for which they earn the same score as every other member of the group	[24, 26]
	Required	Discuss a problem in pairs or groups	[26-28]
	Indicative	Complete specially designed activities to "learn" course concepts on their own without being explicitly told	[26, 27]
	Indicative	Provide answer(s) to a posed problem or question before the class session can proceed	[26]
Cooperative Learning	Required	Participate in group work for which the assessments are designed so that individuals can earn different scores for their work on the assignment	[13, 24, 29, 30]
	Required	Work on problem sets or projects in pairs or small groups	[13, 27, 28, 30]
	Required	Discuss a problem in pairs or groups	[27, 28, 30]
	Indicative	Report their group's findings to the entire class (formally or informally)	[13, 28]
	Indicative	Complete specifically designed activities to "learn" course concepts on their own without being explicitly told	[26, 28]
	Indicative	Provide the answer(s) to a posed problem or question before the class can proceed	[13, 30]

Having students “Participate in activities that engage them in course content through reflection and/or interaction with their peers” is indicative of all RBIS as these are all active learning strategies to improve engagement and was therefore not included in the table.

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Appendix F: Components and I (Indicative) Critical Components with Survey Item numbers listed in the top row and left most column

		4a	4c	4d	4e	4f	4g	4h	4i	4j
		Active Learning	Just-in-Time Teaching	Think-Pair-Share	Concept Tests	Peer instruction	Collaborative Learning	Cooperative Learning	Inquiry Learning	Problem-Based Learning
3a	Watch, listen, and/or take notes on a lecture									
3b	Discuss a problem in pairs or small groups	I		R	I	R	R	R		R
3c	Answer multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student perceptions	I			R	R				
3d	Spent time discussing pre-class assignments which helped you re-evaluate student learning and adjust your lecture "just in time.'	I	R							
3e	Work on projects inspired by problems or situations from real engineering practice	I								
3f	Provide the answer(s) to a problem or question before the class session can proceed	I		R	I	R	I	I		
3g	Work on problem sets or projects in pairs or small groups	I					R	R		R
3h	9. Use clickers to "vote" on the correct answer of a multiple choice question	I			I	R				
3j	Use means other than clickers to "vote" on the correct answer of a multiple choice question									
3k	Complete specifically designed activities to have students 'learn' course concepts on their own without being explicitly told	I					I	I	I	R
3l	Participate in group work for which they earn the same score to every member of the group	I					R			I
3m	Participate in group work for which the assessments are designed so that individuals may earn different scores for their work on the assignment	I						R		I
3n	Report their group's findings to the entire class (could be informally)	I		R		I		I		
3o	Work on problems or projects that require students to seek out new information not previously covered in class	I							R	R
3q	Participate in activities that engage them with course content through reflection and/or interaction with their peers (other than watching, listening and/or taking notes)	R	I	I	I	I	I	I	I	I