Use of Research-Based Instructional Strategies in Core Electrical or Computer Engineering Courses

Jeffrey Froyd, Maura Borrego, Stephanie Cutler, Michael Prince and Charles Henderson

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Introduction

In 1958, Simon Ramo predicted "a new profession known as 'teaching engineer,' that kind of engineering which is concerned with the educational process and with the design of the machines, as well as the design of the material" (Ramo, 1958). Since this prediction, engineering education has undergone and continues to undergo changes (Froyd, Wankat, & Smith, 2012). In the last 100 years, two major shifts have occurred: (i) "curricula moved from hands-on practice to mathematical modeling and scientific analyses" (Froyd, et al., 2012) and (ii) use of learning outcomes to describe educational intent for programs and courses has increased, due principally to the shift to outcomes-based accreditation by ABET (Prados, Peterson, & Lattuca, 2005). Also, three majors shifts are in progress: (i) increasing emphasis on engineering design, (ii) "research on learning and education continues to influence engineering education" (Froyd, et al., 2012), and (iii) computer, communications, and information technologies have created numerous possibilities for innovations in instructional technologies (Froyd, et al., 2012). Through decreases in tenure-track faculty positions and increases in part-time and teaching-focused faculty, a new class of professors of the practice has emerged (Schuster & Finkelstein, 2006; Thedwall, 2008). However, a teaching engineer has not emerged in the past 50 years.

As the shift in which research on learning and education continues to influence engineering education, research on learning has shed light on processes through which people learn and factors that promote and hinder learning (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010; National Research Council, 1999; Svinicki, 2004). Researchers have applied research on learning to create multiple instructional strategies that have demonstrated their efficacy with respect to student learning, particularly in the disciplines of engineering, science, and mathematics. These strategies include learning in small groups (Springer, Stanne, & Donovan, 1999), active learning (Bonwell & Eison, 1991; Prince, 2004), cooperative learning (Johnson, Johnson, & Smith, 2006; Prince, 2004), service learning (Coyle, Jamieson, & Oakes, 2006; Duffy, Barry, Barrington, & Heredia, 2009; Oakes, 2009), peer led team learning (Tien, Roth, & Kampmeier, 2001), peer instruction (Crouch & Mazur, 2001; Mazur, 1997), just-in-time teaching (Novak & Patterson, 1998), and inductive teaching approaches (Prince & Felder, 2006), such as problem based learning, project based learning, inquiry based learning, and challenge based learning. These and other instructional strategies have been advocated in recent reports from the American Society for Engineering Education (ASEE) (Jamieson & Lohmann, 2009, 2012).

Although these instructional strategies have been developed, implemented, and studied extensively, the extent to which faculty members in engineering, science, and mathematics have applied these strategies

has been questioned. Reports suggest that lecture remains the predominant strategy, by large margins (Blackburn, Pellino, Boberg, & O'Connell, 1980; Lammers & Murphy, 2002; Thielens, 1987). Also, a study of science faculty members at three U.S. research universities "indicate[d] that perceived norms for interactive teaching are weak or non-existent, … [while] norms … [for] course content, … instructional autonomy and … course syllabi are present" (Hora & Anderson, 2012). So, there is evidence for predominance of lecture as an instructional strategy and lack of cultural norms supporting interactive strategies. Concurrently, there is substantial evidence on the effectiveness, with respect to student learning, of many alternatives to lecture. Therefore, understanding the extent to which these strategies are adopted (or not) by electrical and computer engineering faculty members, as well as examining how to promote these instructional approaches, may lead to greater understanding of the influences that enhance or reduce likelihood of adoption of research-based instructional strategies (Froyd, Beach, Henderson, & Finkelstein, 2008; Henderson & Dancy, 2009).

One step in this examination would be to provide more data on how electrical and computer engineering (ECE) faculty members are teaching core courses in their curricula. Therefore, the authors have surveyed faculty members to determine how core courses such as circuits and introductory digital logic are being taught. For this paper, the authors have identified a set of instructional strategies that has emerged from research on teaching and learning and will be referred to as Research-Based Instructional Strategies (RBISs) (Henderson & Dancy, 2009). Specifically, the paper asks:

1. What are the levels of awareness and use of RBISs for individual ECE faculty members teaching circuits, electronics, and introductory digital logic or digital design?
2. What barriers to broader adoption of individual RBISs do ECE faculty members report?
3. What factors (such as gender, rank, and job responsibilities) are correlated with an ECE faculty member's level of awareness and use of RBISs?
4. How do ECE faculty members first hear about innovative teaching practices, and how do they pursue additional information about these practices after their initial exposure?

Instead of surveying all ECE faculty members, the authors chose to focus on ECE faculty members teaching selected, core, required courses, usually taught at the sophomore level. One reason is that a survey of all ECE faculty members might include teaching practices in first-year engineering and senior capstone design courses. Instructional practices in these courses often differ from those in required, core courses in the sophomore and junior years. Second, first-year engineering and capstone design courses have been well studied (Bazylak & Wild, 2007; Brannan & Wankat, 2005; Howe, 2010; Howe & Wilbarger, 2006; Todd, Magleby, Sorensen, Swan, & Anthony, 1995). Third, many innovations have occurred in first-year engineering and capstone design courses, while educational practices in core engineering science courses have remained, by and large, unchanged (Froyd, 2005; Froyd, et al., 2012).

Preliminary results that addressed these research questions were presented in a previous conference paper (Borrego, Cutler, Froyd, Henderson, & Prince, 2011), the feedback on which we used to inform this paper. The conference paper combined results from chemical, computer and electrical engineering faculty members, and few meaningful differences by discipline were found. The authors have also published a similar paper on use of instructional strategies by chemical engineering faculty members (Prince, Borrego, Henderson, Cutler, & Froyd, in press). This paper is specifically focused on the electrical

and computer engineering education community and includes additional results from a second wave of data collection.

Literature Review, Part 1: Research on Change in Higher Education

A number of different theories can be used to study various aspects of change in undergraduate engineering education. Diffusion of innovations (Rogers, 2003) is a robust theory that predicts relationships between different awareness and adoption levels and characteristics of innovations[1], the potential adopters, the change agents and their networks. It also includes predictions for change over time, including the stages that potential adopters move through in whether to implement and continue with an innovation, and how an innovation reaches a 'tipping point' of widespread use. It is applied here because a develop-then-disseminate model is the preferred approach of many STEM faculty members, including those who originally developed the RBISs under study (Feser, Borrego, Pimmel, & Della-Piana, 2012; Henderson, Finkelstein, & Beach, 2010).

Innovations in the form of equipment, methods, or research findings, if adopted, follow an S-shaped curve as they are accepted by more and more of the population. A sample adoption S-curve is depicted in Figure 1a. At first, the plot of cumulative users over time is very flat, as just a few innovators learn about and adopt the innovation. As more centrally-involved people become users and their approval is noted by others, the curve arches upward. In the end, only a few late adopters are left, and the curve is again flat. This type of behavior has been observed in adoption of diverse innovations such as farm equipment and cell phones. In most cases, the social network among adopters plays a key role; word-of-mouth conversations and demonstration by current users are the most important means by which knowledge travels and influence is achieved. However, broad adoption (e.g., in Figure 1a, 100% adoption) is not the norm. Alternative scenarios such as Figure 1b are more common, in which adoption decays prior to broad acceptance, and the innovation does not diffuse broadly across through the system. In terms of engineering education, this is what happens when few faculty members discover a classroom practice, and some abandon it after a trial period.

For future diffusion-of-innovations studies, experts Strang and Soule call for "direct contrasts of diffusing practices," specifically "[m]ore attention to how innovations compete and support each other." They go on to emphasize that much could be learned from innovations that fail to fully diffuse and from focusing on the strategies of those seeking to diffuse (Strang & Soule, 1998). The RBISs selected for this study begin to address these issues. Survey responses were collected comparing twelve related RBIS, which compete, at least to some extent, for faculty members' use of class time. The results, as readers will see, demonstrate a broad range of adoption levels at different points on the S-curve.

[1]In the literature on diffusion of innovations, the focus is on many different types of innovations. This literature review will use the term innovations, since that is frequently used in the field. However, for the study described in this paper, innovations being studied are RBISs, and in the rest of the paper the authors use "RBISs" to refer to the innovations being studied.

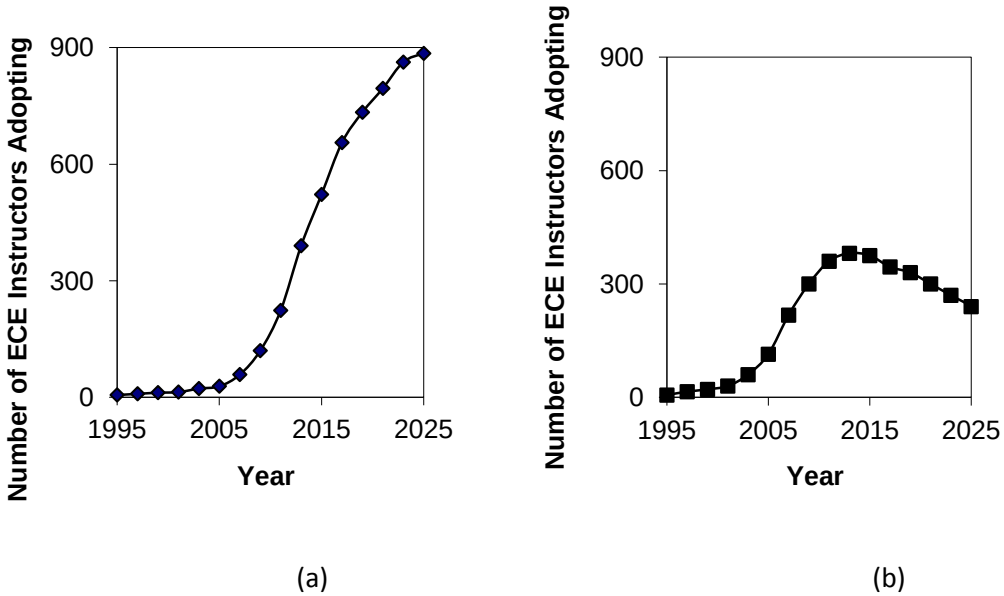

Figure 1. Possible Outcomes of RBIS Dissemination to U.S. ECE faculty teaching core courses. (a) Diffusion of Innovation prediction. This theory predicts an s-shaped curve as the ideas gain momentum. Data adapted from (Rogers, 2003). (b) Alternative prediction. If an idea does not catch on, use of the innovation may decay over time.

Underlying the S-curve is a pattern of adoption with five different groups of adopters in successive stages (Rogers, 2003). Table 1 lists these groups, an estimate of the percentage of the group in the population, and the cumulative percentage of adopters after everyone in the group has adopted the innovation. For example, in this model of adoption the third group to adopt an innovation is referred to as the early majority, which comprises approximately 34% percentage of the population. Further, when the early majority has finished adoption approximately 50% of the population has adopted the innovation. In Figure 1a, this corresponds to 450 ECE faculty members adopting the strategy, between 2004 and 2005. Further, Rogers suggests that by the time the vast majority of the early majority has adopted an innovation (i.e., cumulative adoption about 40-50%), then the innovation will eventually reach saturation in terms of adoption. Although this is an overly simplified model of adoption, it provides a useful lens for viewing adoption of each RBIS. For example, although readers intuitively know that RBISs with higher rates of adoption are more likely to persist, this theory gives credence to the interpretation that those RBISs above 50% adoption may have already reached their tipping point and are more likely to eventually reach full or nearly full adoption. On the other hand, those RBISs with particularly low adoption levels either are not mature enough or will never achieve full adoption.

Table 1. Five Successive Groups of Adopters Underlying the Cumulative Adoption S-Curve.

Group of Adopters	Estimate of the Population	Cumulative Percentage
Innovators	2.5%	2.5%
Early adopters	13.5%	16%
Early majority	34%	50%
Late majority	34%	84%
Laggards	16%	100%

Literature Review, Part 2: Overview of Research Based Instructional Strategies

Since this paper examines adoption of RBISs by ECE faculty members teaching core courses in their curricula, clarification of what the authors mean by RBIS is necessary. To identify RBISs for this study, the following criteria were used:

1. Each RBIS should have documented use in engineering settings at more than one institution.
2. Each RBIS should have demonstrated positive influence on student learning in engineering or STEM.

Applying these criteria led to the selection of the 12 RBIS shown in Table 2. Summaries of research supporting the effectiveness of these specific instructional strategies have been provided (Froyd, 2008; Oakes, 2009; Prince, 2004; Prince & Felder, 2006). Also, descriptions in Table 2 include one or more references for readers interested in more complete descriptions of these instructional strategies and information for applying them in engineering classrooms.

Table 2. Research Based Instructional Strategies (RBIS) and descriptions used in the survey (Citations were added for this publication.). Starred (*) RBIS were included in the physics study (Henderson & Dancy, 2009).

RBIS	Brief Description
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 (Bonwell & Eison, 1991; Buck & Wage, 2005; Felder, 2009; Prince, 2004; Smith, Sheppard, Johnson, & Johnson, 2005)
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; then, calling on students to share their responses (Lyman, 1981)
Concept Tests	Asking multiple-choice conceptual questions with distracters (incorrect responses) that reflect common student misconceptions
Thinking-Aloud-Paired Problem Solving (TAPPS)	Forming pairs in which one student works through a problem while the other questions the problem solver in an attempt to get them to clarify their thinking (Lochhead & Whimbey, 1987)
Cooperative Learning	A structured form of group work where students pursue common goals while being assessed individually (Johnson, et al., 2006)
Collaborative Learning	Asking students to work together in small groups toward a common goal (Bruffee, 1984)
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 (Woods, 2012)
Case-Based Teaching	Asking students to analyze case studies of historical or hypothetical situations that involve solving problems and/or making decisions.
Just-In-Time Teaching (JiTT)*	Asking students to individually complete homework assignments a few hours before class, reading through their answers before class and adjusting the lessons accordingly (Novak & Patterson, 1998)
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 (Mazur, 1997)
Inquiry Learning	Introducing a lesson by presenting students with questions, problems or a set of observations and using this to drive the desired learning (Lee, 2004)
Service Learning	Intentionally integrating community service experiences into academic courses to enhance the learning of the core content and to give students broader learning opportunities about themselves and society at large (Coyle, et al., 2006; Duffy, et al., 2009)

Methodology

A national survey of ECE faculty members who had recently taught a sophomore level engineering science course (circuits, electronics, or introductory digital logic and/or digital design) was completed in the spring of 2011 investigating faculty use of RBIS.

Instrument

This instrument was adapted by the authors from a previous survey of introductory physics instructors (Henderson & Dancy, 2009; Henderson, Dancy, & Niewiadomska-Bugaj, 2012). The instrument was divided into three main parts. The first section asked faculty members about the amount of class time spent on different activities generally associated with RBIS use. The second asked faculty specifically about 12 different RBIS and asked their level of knowledge or use of the each RBIS. Most of the items were multiple-choice, but this section also included some open-ended questions to provide additional clarification. The third section collected demographic information such as gender, rank, and how often they attend talks or workshops about teaching. In this paper, which focuses on reported RBIS use by ECE faculty, the authors report the results of the second and third sections.

Sample

The population for this survey is all faculty members in U.S. ABET-accredited Electrical and Computer engineering programs who had taught sophomore level circuits, electronics, or introductory digital logic and/or digital design in the two years prior to survey administration.

Some potential respondents were identified through an email to all electrical and computer engineering department chairs. In addition, the research team compiled a list of all the ABET accredited Electrical and Computer Engineering programs in the US. From this list, Virginia Tech Center for Survey Research (CSR) contacted each department to identify the instructors for each of the courses of interest.

Survey Administration

In spring 2011, each potential respondent received an email invitation containing a unique survey link so that up to three weekly reminders could be sent to those who had not yet responded. To encourage responses, the e-mail was endorsed and signed by then-President of the IEEE Education Society, and gift cards were offered as raffle incentives to those who completed the survey. To understand potential response bias, a second round of data collection was conducted in fall 2011. Twenty-five faculty members who had not previously completed the survey were contacted via telephone and email and offered a gift card for completing the survey.

There were 130 Electrical and Computer engineering early responses out of 923 contacted faculty members. Of those responses, those who were not teaching the classes of interest or did not complete a majority of the items were not included in the analysis, leaving 115 Electrical and Computer engineers who completed the survey with a response rate of 12.4%. Initial non-respondents were contacted by Center for Survey Research staff and encouraged to complete the survey; 10 additional responses were obtained, of those there were 7 usable responses. There were no significant differences between the early and late respondents with respect to RBIS use. Therefore, the both data sets were combined, bringing the total n to 122 and the response rate up to 13.2%. Demographics of the 122 respondents are

shown in Table 3 in comparison with nationwide demographics. Given the size of the sample, respondent demographics are comparable to national percentages (Yoder, 2011).

Table 3. Demographics of Survey Respondents

National numbers were obtained from the ASEE college profiles report (Yoder, 2011).

	Female	Male	Assistant Professors	Associate Professors	Full Professors	Non-tenure-track	Other
	119 respondents provided gender		121 respondents provided rank				
Survey	20	99	27	39	39	12	4
	16%	81%	22%	32%	32%	4%	3%
Nationwide	14%	76%	18%	24%	42%	10%	6%

Limitations

The survey methodology has at least two limitations, each of which is likely to overestimate actual levels of RBIS awareness and use among ECE faculty members.

The first is fidelity. When faculty members self-report that they are teaching using an RBIS, what they are actually doing in the classroom may not reflect the characteristics that the RBIS developer indicated should be used. Studies in undergraduate biology education have compared faculty self-reports of instructional practices to course observations and found that many faculty members overestimated their use of methods other than lecturing (Ebert-May et al., 2011). Relevant studies of physics faculty draw the same conclusions, including identifying wide variation in faculty ideas of what specific RBIS actually entail (Dancy & Henderson, 2010; Henderson, 2008; Henderson & Dancy, 2009). The authors think it is reasonable to assume similar results in this study.

The second limitation is response bias; that is, with a usable response rate of 13.2%, survey responses may not be representative of the instructional strategies of the broader ECE faculty. In general, it is difficult to estimate the degree to which response bias has skewed the results of any survey, because survey analysts, in general, do not have data on the individuals who did not respond. Survey analysts do not know that for which they have no data. In surveys about health care, survey analysts often have an alternate source of data, i.e., health insurance databases (Etter & Perneger, 1997). However, the authors are unaware of an alternate database that they could use for non-respondents in their study. In fact, the authors had to first create their database of ECE faculty members teaching core ECE courses, because there was no existing database to use.

Given this constraint, several precautions were taken to understand and reduce response bias. First, the research team followed established practices for increasing response rates and working with professionals (Sudman, 1985). Without an alternate database to estimate response bias, a common method of estimating likelihood of response bias influencing results is to compare characteristics of the survey respondents to the general population, and if they are similar, conclude that the effects of response bias are reduced (Groves, 2006). Since the demographics of the survey respondents in this study are similar to the demographics of ECE faculty (Table 3), there is some confidence in the value of

the survey results. Third, following established practice, the survey team did follow up and contact additional ECE faculty members who did not respond to the first rounds of surveys as a way to compare early and late responders to estimate effects of response bias (Ferber, Winter, 1948-1949). In this study, no differences were found between early and late responders that would indicate that response bias influenced results. Finally, the results of this survey are compared to similar studies, and many of the same trends are evident.

The authors think it is reasonable to assume that the ECE faculty members who took the time to respond to this survey about undergraduate education are more interested in the topic than the general population of ECE faculty members. This would mean that they are better informed and perhaps more experienced with the RBIS under study, and that they would respond more positively about RBIS awareness and use.

In sum, there are several reasons to believe that the results of this survey overestimate levels of RBIS awareness and use in the broad ECE faculty population. As a result, the percentages of ECE faculty members using RBISs are better thought of as upper bounds than representative usages. The data are more useful in examining relative levels and relationships between the RBISs, e.g. which are in wider use than others. Finally, the section on barriers to adoption of RBISs is likely to be very relevant to the general ECE faculty, since similar barriers have been described in research on use of RBISs in other disciplines. For these reasons, the authors propose that the results described below can be used, with care, in thinking about adoption of these instructional strategies across ECE faculty members.

Reported Awareness by Named Research Based Instruction Strategy

This section presents results on awareness of RBISs among ECE faculty, and the following section presents results on use. To help readers understand how the authors used survey data to prepare summaries on awareness and use, Table 4 shows how the multiple choice options for each RBIS were mapped to awareness and use. The left-hand column shows the six (6) multiple choice options that survey respondents could use to describe their level of knowledge about a RBIS. The second column shows how the authors mapped the multiple choice options to the levels of awareness used in Figure 2: familiar, heard name only, and unaware. The third and fourth columns show how the authors mapped the multiple choice options into the three descriptions of use in the next section: currently use, tried but stopped, and familiar but never used. Also, the last row describes how the denominator for the percentage calculations was obtained.

Table 4. Mapping Survey Responses to Percentage Calculations.

Multiple Choice Option	Figure 2	Figure 3	Table 5
1.I Currently Use It	Familiar	Currently use*	Currently use
2.I Have Used it in the Past		Tried but stopped	Tried but stopped
3.I Have Used Something Like it But Did Not Know Name			
4.I am Familiar with It, But Have Never Used It		Familiar but never used	(Not included)
5.I Have Heard Name, But Know Little Else About It	Heard name only	(Not included)	
6.I Have Never Heard of It	Unaware		
(Denominator for percentage calculations)	All responses, 1-6	1-4	1-3

*Respondents who choose the item "have used something like it" may still be using their instructional strategies, and could be placed in the category "currently use". For Figure 3, the choice was made to be on the conservative side for estimating percentages for "currently use".

Before ECE faculty members can decide to apply a specific RBIS in courses they teach, they must learn about its existence. Figure 2 shows reported percentages of respondents who were familiar, heard name only, and unaware for the RBISs in this study. The RBISs are listed in descending order of familiarity. Percentages of familiarity ranged from 93% (collaborative learning) to 50% (just-in-time teaching). Familiarity is at or above 69% for all but two of the RBISs: thinking aloud paired problem solving and just-in-time teaching. Active learning and collaborative learning would be expected to be the highest because they embrace many different teaching approaches and they have been published for decades in many different venues. Awareness levels of RBISs such as thinking aloud paired problem solving, concept tests, and peer instruction would be expected to be lower because they are specific teaching approaches and are newer than active or collaborative learning. Even if the actual levels are not quite as high as these survey results, awareness of RBISs appears to be sufficiently high that adoption would be primarily determined by whether ECE faculty members decide to apply the strategies they know about.

A survey of physics faculty members provides a basis for comparison of these awareness levels (Henderson, et al., 2012). Unlike the ECE faculty survey, the physics survey asked only about specifically named instructional strategies, such as peer instruction and just-in-time teaching. The physics survey did not include broad categories of instructional strategies such as active learning, collaborative learning, and cooperative learning. In the physics survey, the RBIS with the highest level of awareness was peer instruction (64%), which is reasonable because the person who named peer instruction, Eric Mazur, is a well-known figure in the physics community. Just-in-time teaching was the fifth highest with 48% awareness (almost exactly the same as level of familiarity among ECE faculty members).

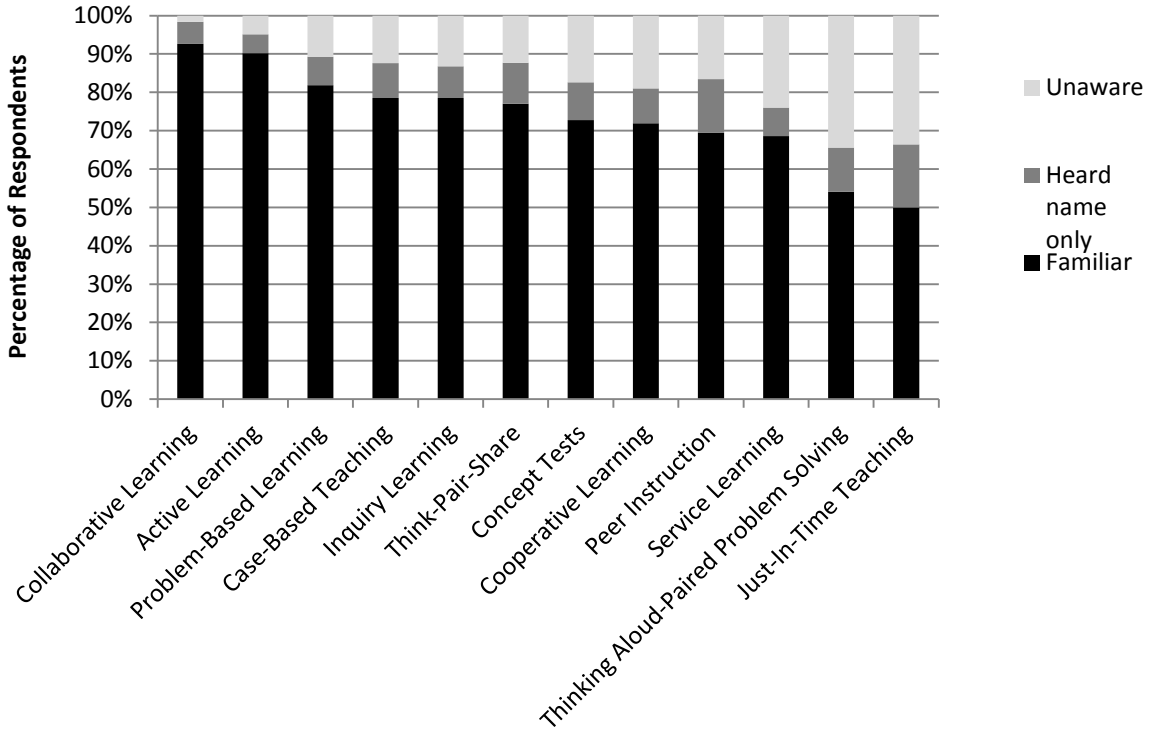

Figure 2. Percentages of Awareness of RBISs among ECE Faculty Members Teaching Core ECE Courses.

Reported Use by Research Based Instruction Strategy

Once transitions to familiarity with one or more RBISs have been made, questions about ECE faculty members' use of RBISs can then be addressed. Figure 3 shows a summary of use of RBIS among survey respondents, specifically the subset of respondents who indicated they were familiar with the RBIS. Table 4 shows how the survey responses were converted into the categories and percentages displayed. The RBIS are listed in descending order of ever used (the sum of "currently use" and "tried and stopped"). The relative ranking of the RBISs generally follows that of awareness in Figure 2, with a few notable exceptions. Just-in-time teaching moved up significantly, while case-based teaching moved down significantly. As this is a comparison of awareness to trial, these two RBISs have characteristics that influence faculty members' willingness to try them in their engineering science courses. In this case, it may be that just-in-time teaching was developed specifically for large lecture introductory courses (and associated materials may be more readily available), while case-based teaching is more obvious fit to upper-division engineering courses. This explanation holds also for additional RBIS which shifted less dramatically in their relative ranking between Figures 2 and 3. Inquiry learning and thinking-aloud paired problem solving, developed for introductory courses, moved up in the ranking. Project-based learning and service learning moved down; while these are being implemented in engineering courses, they may be more prevalent in first-year and capstone courses.

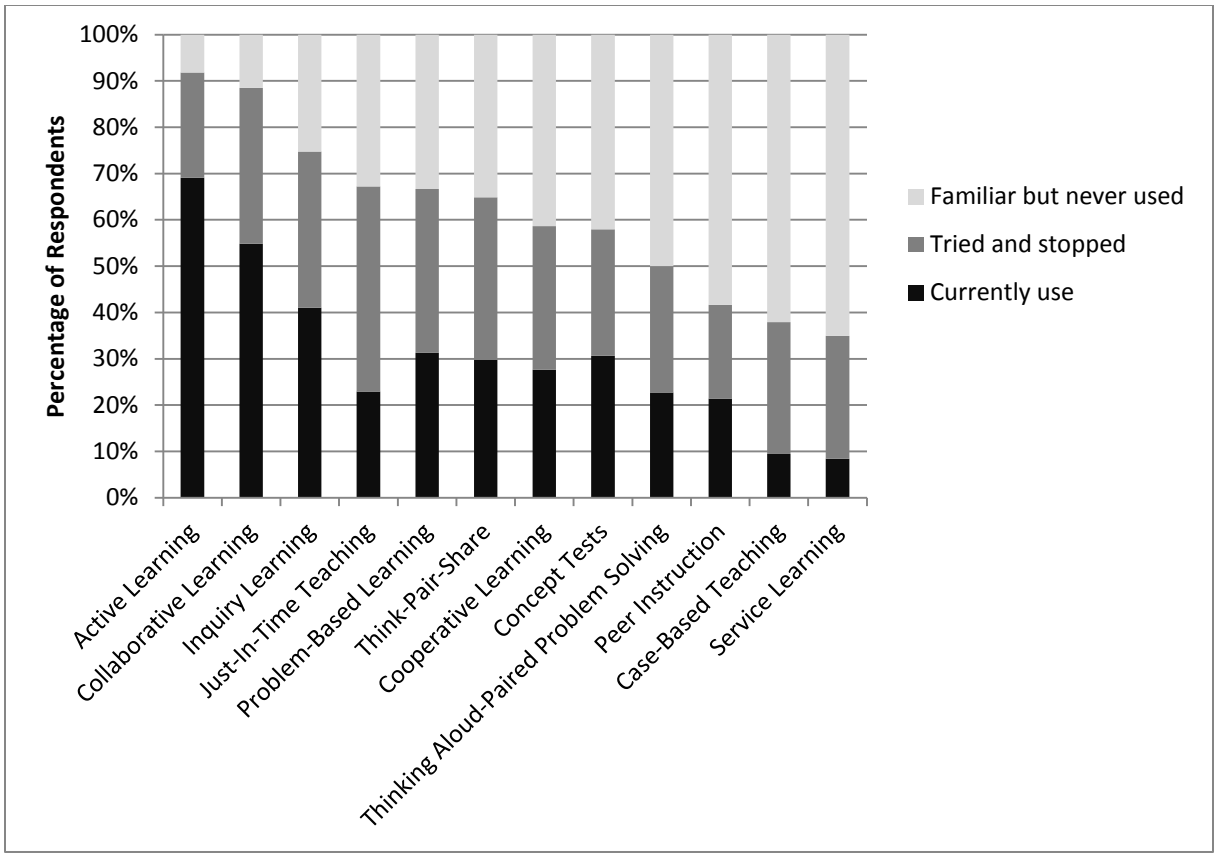

Figure 3. Percentages of RBIS Use among ECE Faculty Members Teaching Core ECE Courses.

There may be a different set of characteristics which influences whether faculty members will continue to use an RBIS after they try it. To take into account varying percentages of ECE faculty members who have tried a RBIS (as opposed to the percentages who were familiar with a RBIS, which provide the denominators for the percentages in Figure 3), Table 5 shows the percentage of ECE faculty members who have tried and stopped (based on a total of current users + those who have tried and stopped). Using this percentage, RBISs with very high rates of discontinuation are service learning (76%) and case-based teaching (75%), while the RBIS with the lowest rates of discontinuation is active learning (25%). This would be consistent with the characteristics of these teaching approaches since preparation time and resources required for service learning and case-based teaching are high while preparation time and resources for active learning are among the lowest of all RBISs. However, it is important to understand whether ECE faculty members perceive these same barriers in making their decisions to try or continue an RBIS.

Table 5. Percentage of ECE Faculty Members Who Tried a RBIS and Stopped Using It (as a percentage of ECE faculty members who have ever tried the RBIS)

RBIS	Percentage
Service Learning	76%
Case-Based Teaching	75%
Just-In-Time Teaching	66%
Thinking Aloud-Paired Problem Solving	55%
Think-Pair-Share	54%
Problem-Based Learning	53%
Cooperative Learning	54%
Peer Instruction	49%
Concept Tests	47%
Inquiry Learning	45%
Collaborative Learning	38%
Active Learning	25%

Reported Barriers to Adoption

What are the barriers to adoption? The survey provided respondents the opportunity to describe barriers to adoption for each of the twelve RBISs. Respondents could describe barriers for individual RBIS. Responses were coded, grouped into categories, and number of responses counted. Since a respondent might list the same barrier for each RBIS, the total number of times a barrier could be mentioned is the number of respondents (122) times the number of RBISs (12) or 1464. Six categories were most frequently mentioned, and the results are summarized in Figure 4. The most frequently mentioned barrier is concern that use of a RBIS will consume class time. Class time is mentioned 407 times or 28% of the possible mentions. Authors infer that respondents are concerned that use of class time is a threat to content coverage, which prior work has identified as a principal concern of faculty members about using a RBIS (J. L. Cooper, MacGregor, Smith, & Robinson, 2000; M. M. Cooper, 1995; Felder & Brent, 1999). The second most frequently mentioned barrier is preparation time (249 mentions or 17% of the possible mentions). These two are the most frequently mentioned barriers by chemical engineering faculty members (Prince, Borrego, Henderson, Cutler, & Froyd, in press) and physics faculty members (Dancy & Henderson, 2010). Surprisingly, the least frequently mentioned concern is resources (other than time), which was mentioned only 34 times or 2% of the possible mentions.

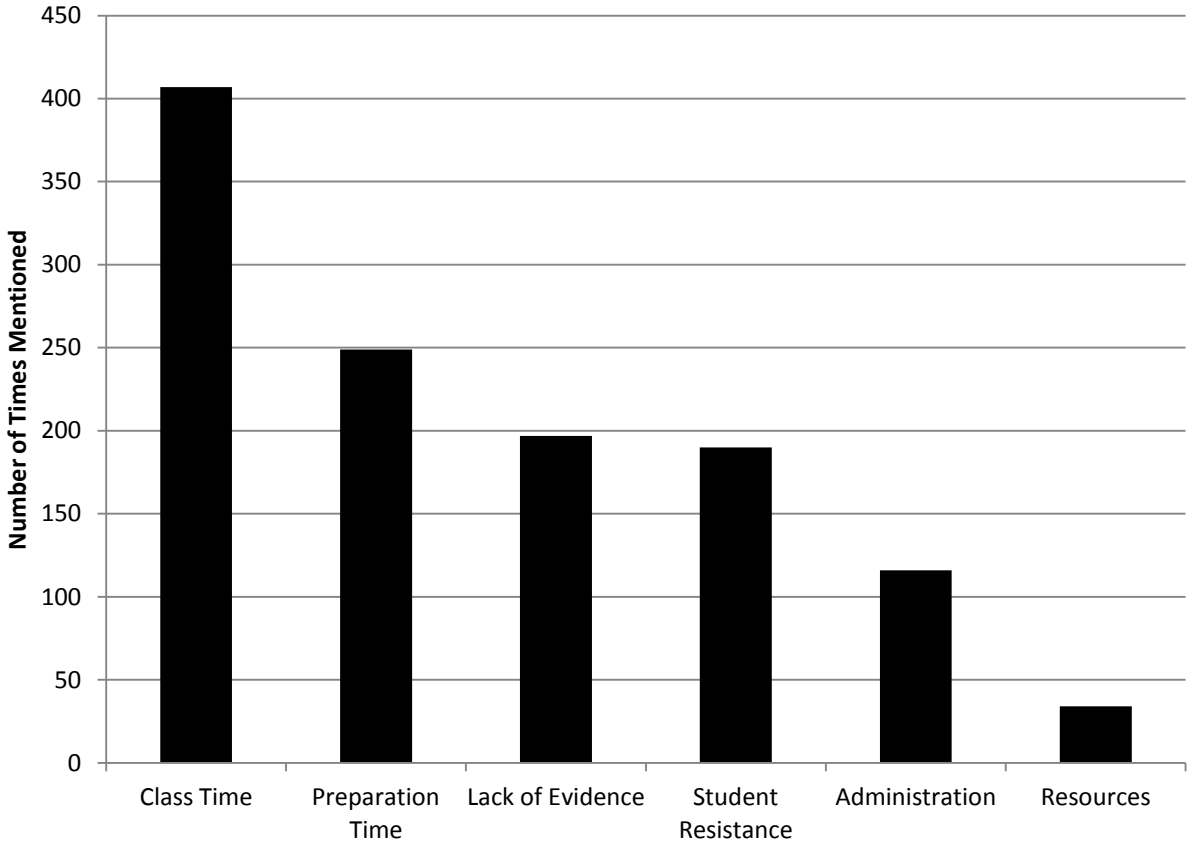

Figure 4. Barriers to Adoption of All RBIS among ECE Faculty Members Teaching Core ECE Courses.

Mentions of lack of evidence might be indicative of respondent unfamiliarity with the literature, given the number of different studies across multiple contexts.

Discussions of faculty change inevitably include calls to alter faculty reward systems to help promote adoption of teaching approaches other than lecture (Brand, 1992; Fairweather, 2008; Jamieson & Lohmann, 2012). Thus, identification of faculty reward systems as an important barrier would be expected in these results. In contrast, faculty reward systems were not mentioned as a major barrier by survey respondents. Administration ("My department and administration would not value it") was the fifth most frequently indicated barrier in the survey, cited less than 2/3 as frequently as these others (Figure 4). Respondents also had opportunities to identify faculty rewards as barriers to adopting RBISs through open ended responses. However, only two (see below) mentioned that lack of recognition inhibited adoption of one or more RBIS. On the other hand, the second most frequently cited barrier is preparation time, again less than 2/3 as frequently cited as the top barrier. Class preparation competes for faculty time against research and other activities. If ECE faculty members perceive the need to attend to activities that will produce results that are more valued by reward system (e.g., research proposals, journal papers), then it could appear in the survey results as a high frequency of "Too much advanced preparation time required." Yet it is worth noting that barriers related to class time, evidence

of RBIS efficacy, and student resistance were more salient than some of these indicators of the faculty reward system.

Figure 5 decomposes mentions of barriers by RBIS. To compute percentages for an RBIS the denominator is the overall number of times any barrier was mentioned for that RBIS. Consistent with Figure 4, the most frequently mentioned barrier for any RBIS is class time, and the least frequently mentioned barrier is resources, even for service learning where resources might be expected to present a significant barrier to implementation. The second most frequently mentioned barrier varies among preparation time, lack of evidence, and student resistance.

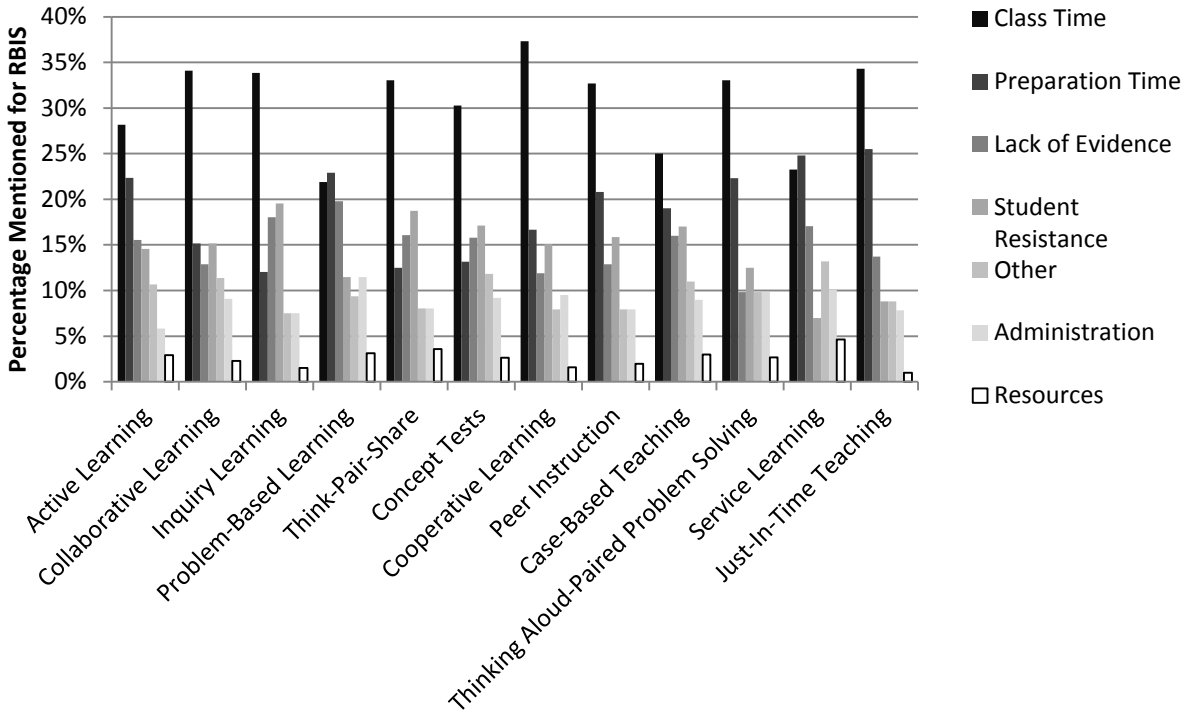

Figure 5. Barriers to Adoption of Individual RBIS among ECE Faculty Members Teaching Core ECE Courses.

To provide more in-depth understanding about the barriers that ECE faculty mention with respect to using one or more RBISs in their courses, for each RBIS the survey asked an open-ended question: "Please specify any factors that seriously discourage any potential plans for using this particular teaching strategy in the future: [each RBIS]". For each RBIS only 5-8 respondents provided open-ended responses. Issues, other than those already listed in the survey, that were raised by multiple respondents include the following:

- Five respondents mentioned that large enrollment courses hinder use of one or more of the RBISs.
- Two respondents mentioned that they would be more likely to try one or more RBISs if they received recognition for their initiative, e.g., in their annual review.

- Two respondents mentioned student resistance. One said that students complained because attendance became more important if an RBIS was being used. Another said that "stronger students pushed back" against RBIS implementation.

Also, some respondents understood one or more of the RBISs in ways that are odds with more commonly accepted interpretations. For example, when asked about factors that would discourage implementation of active learning, one respondent mentioned the cost of clicker systems. Since active learning can be implemented in many ways that do not require clicker hardware, this respondent may have interpreted active learning more narrowly than interpretations that are presented in many papers on active learning. This may explain why in Figure 5, think pair share is one of the most resource-intensive RBIS (second only to service learning). This perception of active learning as requiring costly equipment is consistent with results of the authors' prior study of engineering department heads (Borrego, Froyd, & Hall, 2010).

Factors Influencing Use of RBIS

The research team examined relationships between:

(i) Use of classroom practices and use of RBISs, and
(ii) Factors mentioned in the literature as influencing teaching.

The list of potentially influencing factors was:

(a) Attended National Effective Teaching Institute (NETI) (Felder & Brent, 2010)
(b) Attended other one-day or longer teaching workshops
(c) Attended teaching talks
(d) Gender
(e) Rank
(f) Talks to colleagues about teaching
(g) Job responsibilities with respect to teaching

To address research question 3 (demographic and job factors that correlate with awareness and use of RBIS), Chi Square analysis or Fisher's exact test was used, depending on the cell size. All comparisons were based on 2x2 matrices created by combining responses. For example, for each RBIS, only current users where considered to be "Users"; all other responses were considered "Non-Users." Significance was determined using an alpha of 0.01 due to the large number of comparisons. All calculations were completed using SPSS statistical software. Table 6 shows the only statistically significant relationships from the survey response data. There were 96 statistical tests comparing 8 factors to 12 RBIS; only 6 significant relationships were found.

Table 6. Factors Influencing Use of RBIS

RBIS	Influencing Factor	RBIS Users in each group	p-value
Think-Pair-Share	Gender	65% of female faculty members 15% of male faculty	< 0.001
Think-Pair-Share	Talks to Colleagues about teaching	42% of those who talk to colleagues weekly or more often 16% of those who talk to colleagues once a semester or year	0.002
Thinking Aloud Paired Problem Solving	National Effective Teaching Institute (NETI)	63% of those who attended NETI 9% of those who did not attend	0.001*
Active learning	Attended teaching talks	86% of those who attended 4 or more teaching talks on campus in past year 55% of those who attended 3 or less	0.004*
PBL	Attended teaching talks	46% of those who attended 4 or more teaching talks on campus in past year 19% of those who attended 3 or less	0.004
Just-in-time Teaching	Rank	23% of untenured (adjunct and assistant professors) 6% of tenured (associate and full professors)	0.008

* indicates Fischer's Exact Test was used

Most of these relationships are in the expected direction. Faculty members who attend workshops and discuss their teaching are more likely to use certain RBISs. Female and untenured faculty members were also more likely to use some RBISs. What is more interesting about these results is that there were not more statistically significant relationships, and that some frequently cited factors, such as the percentage of job responsibilities represented by teaching, were not significant for any RBIS.

In a conference paper, a different analysis of this data was presented to make more direct comparisons to physics survey results (Cutler, Borrego, Henderson, Prince, & Froyd, 2012; Henderson & Dancy, 2009). For both engineering and physics faculty members, attending presentations about teaching supported trying RBISs and continuing their use. Attending the New Physics and Astronomy Faculty Workshop or the National Effective Teaching Institute supported continued use of RBISs (Felder & Brent, 2010; Henderson, 2008; Henderson, et al., 2012). Both studies revealed differences by gender but at different stages. Female engineering faculty members were more likely than men to try RBISs, while female

physics faculty were more likely than men to continue using a RBIS after trying and to use multiple RBIS (Henderson, et al., 2012).

How ECE Faculty Members Find Information about RBISs

Given the significant differences related to conversations with colleagues about teaching and attendance at workshops, it would be important to know where ECE faculty get their information about RBISs. Table 7 summarizes survey data about how ECE faculty members found out about the different RBISs. RBISs in Table 7 are ordered by descending percentage of current use.

Table 7. How ECE faculty first found out about specific instructional strategies. Participants selected one option. This question only allowed one response per strategy.

	Number of Responses (one response per strategy)	Do not recall	Read article or book about it	Colleague (word of mouth)	Presentation or workshop on my campus	other	Presentation or workshop at an engineering education conference (e.g., FIE, ASEE)	In-depth workshop of one or more days (e.g., NETI, NSF-sponsored)	Presentation or workshop at my professional society conference (e.g., AIChE)
Active Learning	110	24%	13%	22%	14%	12%	10%	6.4%	0.0%
Collaborative Learning	115	31%	14%	16%	16%	10%	6.1%	7.0%	0.0%
Inquiry Learning	101	44%	19%	12%	9.9%	7.9%	5.9%	2.0%	0.0%
Problem-Based Learning	104	25%	18%	13%	15%	11%	12%	2.9%	2.9%
Concept Tests	93	28%	12%	22%	7.5%	16%	12%	3.2%	0.0%
Think-Pair-Share	104	38%	12%	13%	16%	8.7%	8.7%	4.8%	0.0%
Cooperative Learning	94	35%	17%	14%	14%	7.4%	7.4%	5.3%	0.0%
Just-In-Time Teaching	81	35%	15%	11%	14%	6.2%	11%	6.2%	2.5%
Thinking-Aloud-Paired Problem Solving	74	35%	11%	16%	11%	9.5%	9.5%	4.1%	4.1%
Peer Instruction	96	28%	15%	19%	13%	11%	10%	3.1%	1.0%
Service Learning	87	33%	14%	17%	17%	9.2%	5.7%	1.1%	2.3%
Case-Based Teaching	98	50%	18%	9.2%	8.2%	6.1%	5.1%	2.0%	1.0%
Cumulative (across all RBISs)	**1157**	**34%**	**15%**	**15%**	**13%**	**9.7%**	**8.6%**	**4.1%**	**1.0%**

For the initial source of information about a RBIS, the most frequent response selected (ranging from 25% to 50% of respondents) was “do not recall”. The next most frequent source of information was either a colleague or an article in a book or journal, except for collaborative learning and service learning where colleague was tied with on-campus event (presentation or workshop) and think-pair-share where on-campus event was the second most frequently cited source. The importance of colleagues is emphasized in these results; trusted colleagues can be critical in encouraging a faculty member to seek more information about instructional strategies. In sum, engineering education scholars tend to focus on conference papers and journal articles to propagate their findings, but the results reported here underscore the importance of local colleagues and on-campus events. In fact, frequent collegial

discussions are mentioned in the literature as an activity to help faculty members think through how they might implement instructional strategies, experiment, and improve their approaches over time (Wieman, Perkins, & Gilbert, 2010; Wright, 2005). "Faculty also mention two important implicit rewards: 1) seeing how much more engaged students can become, and 2) being able to think about and discuss teaching with their colleagues as a serious scholarly activity. Faculty who have experienced these rewards and are vocal about their experiences have been a force for change" (Wieman, et al., 2010, p. 13).

Discussion and Conclusions

This paper reported results of a national survey of ECE faculty teaching circuits, electronics, and introductory digital logic or digital design at U.S. institutions intended to address the research questions posed in the introduction. Awareness levels for the 12 RBISs were high, reinforcing previous findings that significant barriers to broader adoption occur at later stages in the process as faculty members consider whether to try and later continue or discontinue using a specific RBIS (Cutler, et al., 2012; Prince, et al., in press).

There was far more variation across the RBISs in levels of use and percentages of faculty who had tried but abandoned different RBISs (discontinuation). Active and collaborative learning had the highest levels of awareness and use, and the lowest rates of discontinuation. These two RBISs have been documented in the literature for the greatest length of time and require few resources to implement. Inquiry learning and problem-based learning had high awareness and use but roughly 50% discontinuation. Service learning and case-based teaching had the highest rates of discontinuation, 75% or more. Percentages of current use for both are below 10% suggesting that only innovators and less than half of early adopters are applying either in their courses. These two RBIS require significant resources including instructor time, and current curricular materials do not support their use in the core engineering science courses in this study.

Although respondents had the option to indicate different barriers for different RBISs, there were few deviations from the overall trend in Figure 4. Class time was by far the most frequently cited barrier. In the immediate future, resources and preparation approaches should be formulated so that faculty members' perceptions of time required drop low enough to convince them to try (or retry) RBISs in their courses. The literature is variable in its claims of how much class time various RBISs will take, in part because it is dependent on how faculty members choose to implement them. The issue may be more complex than simply repairing faculty misperceptions.

A more important result related to barriers was that there was limited evidence to support the widely-touted notion that the faculty reward system is the primary barrier to improving instruction in undergraduate engineering education. Only two respondents wrote open-ended comments related to credit for teaching improvements in their annual reviews. Rewards and values may manifest themselves in pressures for how to spend one's limited time, particularly class preparation time, which could be spent on research instead. However, this barrier was a distant second to concerns about class time, and pressure from administrators was fifth after lack of evidence and student resistance. These results

suggest that faculty members' orientation toward content coverage and their beliefs about student learning are more critical barriers to widespread adoption than promotion and tenure.

Based on the rates of current use presented in Figure 3, ranging from 8% to 69%, these RBISs span the S-curve presented in Figure 1. At 69% and 55%, active and collaborative learning are farthest along and arguable past the 50% tipping point that presages widespread adoption. Both have been documented in the literature since at least 1981. In contrast, TAPP has been documented for at least as long but has not seemed to have gained traction in ECE (23% of respondents currently use it). This low rate of use, coupled with its 55% discontinuation rate, may indicate that TAPP's adoption curve in ECE will more closely resemble Figure 1b. Case-based teaching and service learning are more recent developments, but their discontinuation rates in excess of 75% argue against their widespread adoption, at least in core ECE engineering science courses. Current use and discontinuation rates for other RBISs, such as JiTT and concept tests, make predictions about adoption questionable, even as developers are actively working to create and archive engineering-specific resources for use in engineering science courses.

Of course, predictive inferences should be interpreted cautiously, as suspected response bias suggests that actual rates of awareness and use of RBISs by ECE faculty are lower than presented in this paper. Future work should take into consideration challenges described in this paper to accurately measuring rates of adoption of RBIS in undergraduate education. Some analyses can be designed so that they do not rely on generalizable adoption rates, such as examining relationships between other variables.

Nonetheless, the survey results presented here are a starting point, providing some empirical data and links to theory and literature to see increasingly sophisticated discussions and investigations of instructional practice in undergraduate STEM education.

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