USE OF RESEARCH-BASED INSTRUCTIONAL STRATEGIES

in Core Chemical Engineering Courses

Michael Prince[1], Maura Borrego[2], Charles Henderson[3], Stephanie Cutler[2], and Jeff Froyd[4]
[1] *Bucknell University*
[2] *Virginia Tech*
[3] *Western Michigan University*
[4] *Texas A&M University*

Increasingly, high-profile organizations including the American Society for Engineering Education,[1] National Academy of Engineering,[2-4] Association of American Universities,[5] National Research Council,[6-8] and the National Science Board[9, 10] are calling for widespread improvements in undergraduate STEM education. Tremendous effort over the past few decades has built up a substantial knowledge base about STEM learning and research-based instructional strategies[11] such as active learning,[12] cooperative learning,[12] problem-based learning,[13] and service learning.[14] Yet these prestigious groups are increasingly expressing dissatisfaction with the rate of implementation of research-based instructional strategies.

Given this situation, it appears that the greatest impediment to improving engineering education lies not in finding more effective instructional strategies but in increasing the use of those strategies already known to be more effective than the traditional methods still found in most undergraduate classrooms.[15] Understanding how to promote broader use of research-based instructional strategies in undergraduate engineering classrooms is therefore a critical challenge requiring more attention.[11, 16]

To be effective, future efforts must be informed by 1) knowledge of effective mechanisms for making faculty aware of the relevant research, 2) information on the current adoption rates of specific strategies by engineering faculty members, and 3) understanding of factors that hinder broader adoption of each strategy in undergraduate engineering classrooms. This paper draws on a survey of 99 instructors of core undergraduate chemical engineering courses to examine these issues. The core engineering courses selected for study were fluid mechanics, thermodynamics, and heat/mass transfer since these courses are common to most chemical engineering programs. Specifically, the paper asks:

1. *What are the levels of awareness and use of specific research-based instructional strategies for chemical*

Michael Prince *is the Rooke Professor of Engineering at Bucknell University. His research interests include assessment and repair of persistent student misconceptions, examining factors that promote students' self-regulated learning competencies, and exploring how to increase the diffusion of educational research into educational practice. He received his B.S. in chemical engineering from Worcester Polytechnic Institute and his Ph.D. in chemical engineering from U.C. Berkeley.*

Maura Borrego *is an associate professor in the Department of Engineering Education at Virginia Tech, currently serving as a program director at the National Science Foundation. Her research interests include engineering faculty development, specifically how faculty members decide to apply the results of educational research, and interdisciplinary graduate education in STEM. She holds M.S. and Ph.D. degrees in materials science and engineering from Stanford University.*

Charles Henderson *is an associate professor at Western Michigan University (WMU), with a joint appointment between the Physics Department and the WMU Mallinson Institute for Science Education. He is the senior editor for the journal* Physical Review Special Topics - Physics Education Research. *Much of his research activity is focused on understanding and improving the slow incorporation of research-based instructional reforms into college-level STEM courses. He holds a Ph.D. in science education from the University of Minnesota.*

Stephanie Cutler *is a Ph.D. candidate in the Department of Engineering Education at Virginia Tech. Her dissertation will focus on how engineering education research is adopted into practice, specifically how Research Based Instructional Strategies are implemented in the statics classroom. She received her B.S. in mechanical engineering from Virginia Commonwealth University and her M.S. in industrial and systems engineering with an emphasis on human factors from Virginia Tech.*

Jeffrey E. Froyd *is a TEES research professor in the Office of Engineering Student Services and Academic Programs at Texas A&M University. His research interests include curricular and organizational change, engineering faculty development, integrated curricula and learning communities, and metacognitive development of engineering students. He received his B.S. in mathematics from Rose-Hulman Institute of Technology and his M.S. and Ph.D. degrees in electrical engineering from the University of Minnesota.*

engineering faculty members teaching fluid mechanics, thermodynamics, and heat/mass transfer?

2. *What factors (such as gender, rank, and job responsibilities) are correlated with a chemical engineering faculty member's level of awareness and use of each strategy?*
3. *How do chemical engineering faculty members first hear about research-based instructional strategies and how do they pursue additional information about these strategies after their initial exposure?*
4. *What barriers to broader adoption of research-based instructional strategies do chemical engineering faculty members report?*

Preliminary results were presented in a previous conference paper,[17] the feedback on which we used to inform this paper. The conference paper combined results from chemical, computer, and electrical engineering faculty members, and we found few meaningful differences by discipline. This paper provides an expanded and substantially different introduction, literature review, and discussion of the chemical engineering results specifically targeted to the chemical engineering education community. This paper also includes additional data from a second wave of data collection.

PREVIOUS RESEARCH

Studies examining adoption rates of research-based instructional strategies in chemical engineering fit within a larger body of literature on the diffusion of innovations.[18-20] Several relevant findings emerge from this broader literature. First, individuals do not make decisions about adopting an innovation (*e.g.*, an instructional strategy) all at once. Instead, they follow a fairly common progression of stages:

1. *Awareness – individual learns about the innovation*
2. *Information – individual seeks for more information*
3. *Reflection – individual sifts through pros and cons*
4. *Adoption (or Rejection) – individual tries the innovation (or not) and analyzes results*
5. *Follow-up – individual makes decisions about continuing (or not) to apply the innovation*

While the number and description of the stages differ across various adoption models, the finding that adoption occurs in stages is common. This influenced our decision to differentiate between awareness and adoption of strategies in our survey and our subsequent report of the findings.

Second, characteristics of the instructional strategy impact adoption rates. Not surprisingly, if the strategy is more consistent with what the individual (and the department) values and has experienced, then it is more likely to be adopted by that individual. Also, if the instructional strategy is easier to apply, its likelihood of adoption is higher. Prior work has shown that faculty members have a common set of concerns about adopting new strategies:

(a) *Will I still be able to cover the content?*[21-23]

(b) *How much work do I need to do to apply the strategy?*

(c) *How will my students respond?*[22]

(d) *How will my colleagues respond?*[24] *and*

(e) *How well does the innovation fit with constraints of my course,* e.g., *enrollment, classroom size, classroom configuration, and length of class periods?*[23, 24]

Third, individuals learn about the innovation through different channels, which are more (or less) appropriate at different stages of adoption. Communication channels can be characterized as mass media or interpersonal. Mass media includes journal articles, conference publications, and professional society publications such as ASEE's *Prism*. Interpersonal channels include having an informal conversation with someone describing his or her positive experience with an instructional strategy. Faculty workshops such as the National Effective Teaching Institute[25] are more efficient than one-on-one conversations, but provide similar personalized experiences and advice. Rogers explains that mass media channels are more important at the awareness stage, while interpersonal channels are critical at the evaluation stage.[20] More specifically, "...the heart of the diffusion process is the modeling and imitation by potential adopters of their near peers' experiences with the new idea. In deciding whether or not to adopt an innovation, individuals depend mainly on the communicated experience of others much like themselves who have already adopted a new idea. These subjective evaluations of an innovation flow mainly through interpersonal networks."[18]

Building on this previous research, a survey was conducted in 2009 of 197 U.S. engineering department chairs regarding their personal awareness and their department's adoption of seven engineering education interventions.[20] The chairs estimated that, on average, 36% of their engineering faculty members were using research-based instructional strategies (labeled "student-active pedagogies" in the chairs survey).

Analysis of open-ended survey responses from department chairs helped to identify some of the primary barriers to propagation of educational research into the classroom. Department chairs cited financial resources, class sizes, space constraints, technology limitations, faculty time, student learning, and fears of student resistance as considerations. These concerns were frequently framed as weighing benefits against costs. Some survey comments also indicated that the innovations were perceived to be more complex than is necessarily the case, suggesting the need for further education and faculty development efforts. For example, many chairs suggested that active learning requires costly technology when in fact many forms of active learning require no additional resources. Although that study offered insights into how department chairs perceive research-based instructional strategies as well as factors that promote and hinder adoption, studies that solicited data directly from engineering faculty members are warranted to provide a more comprehensive picture of instruction in engineering classrooms.

RESEARCH METHODS

To begin to explore how these issues apply to U.S. chemical engineering faculty members, we conducted a national survey focusing on 12 research-based instructional strategies.

Research Based Instructional Strategies (RBIS)

Table 1 lists the research-based instructional strategies examined in this study. These were selected because they have documented use in engineering settings at more than one institution and demonstrated positive influence on student learning in engineering or STEM. Definitions for each strategy, as well as attempts to clarify distinctions between similar strategies such as collaborative vs. cooperative learning or problem-based vs. project-based learning, were drawn from the following references: active learning,[12, 26, 27] think-pair-share,[26, 28] concept tests,[26] TAPPS,[26] cooperative learning,[12, 29] collaborative learning,[12, 30] problem-based learning,[12, 13, 31, 32] project-based learning,[13] case-based teaching,[13] just-in-time teaching,[33] peer instruction,[34] inquiry learning,[13, 35] and service learning.[36, 37] Summaries of research supporting the effectiveness of these specific instructional strategies are provided in Prince,[12] Prince and Felder,[13] and Oakes.[14]

Instrument

The survey instrument was divided into three sections. The first section asked faculty about the amount of class time spent on different activities generally associated with each instructional strategy. The second asked faculty specifically about their knowledge or use of each of the targeted 12 strategies. Respondents were provided with the definitions of the RBIS in Table 1. The third section collected demographic information such as gender, rank, and frequency of attendance at teaching workshops. Due to space constraints, we report here the results from the second and third sections, reserving comparison between the first and second sections for a future publication.

The survey instrument was adapted by the authors from a previous survey of introductory physics instructors.[11, 38] The physics instrument and a description of its development can be found elsewhere.[11] The overall instrument reliability for the chemical engineering survey is indicated by a Cronbach alpha of 0.755, which is within the commonly acceptable range.[39]

Sample

The population for this survey is all faculty members in ABET-accredited chemical engineering programs who had taught sophomore-level introductory thermodynamics, fluid mechanics, and/or heat transfer in the last two years. A few potential respondents were identified through an e-mail to all chemical engineering department chairs. Then, the Virginia Tech Center for Survey Research contacted all 158 programs

TABLE 1
Research-Based Instructional Strategies (RBIS) and Descriptions To Be Used in the Survey

RBIS	Brief Description
Collaborative Learning	Asking students to work together in small groups toward a common goal.
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.
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.
Inquiry Learning	Introducing a lesson by presenting students with questions, problems, or a set of observations and using this to drive the desired learning.
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.
Cooperative Learning	A structured form of group work where students pursue common goals while being assessed individually.
Case-Based Teaching	Asking students to analyze case studies of historical or hypothetical situations that involve solving problems and/or making decisions.
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.
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.
Thinking-Aloud-Paired Problem Solving	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.
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.

via telephone with e-mail follow-up to identify the names and e-mail addresses of faculty who met the selection criteria. Ultimately, 505 faculty members were identified as potential participants.

Survey Administration

In spring 2011, the Center for Survey Research sent e-mail invitations to each of the instructors. Each person received a unique survey link so that up to three weekly reminders could be sent to those who had not yet responded. To increase the response rate, the e-mail was endorsed and signed by a member of the survey committee of AIChE and gift cards were offered as raffle incentives to those who completed the survey. The survey was sent to a total of 505 ChE faculty members. There were 108 responses. After removing 15 who did not teach the courses of interest and others who did not answer a majority of the items, we were left with 92 usable responses for a response rate of 19%. 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 e-mail and offered a gift card for completing the survey. Four respondents did not teach the course of interest, but an additional seven usable responses were obtained. The two data sets were combined because statistical comparison using Fisher's exact test revealed no significant differences; bringing the overall response rate to 20%.

Data Analysis

Most of the data presented here consist of simple descriptive totals and percentages of various responses. In some cases, response categories were combined. To address research question 2 (demographic and job factors that correlate with awareness and use of instructional strategies), we used a Fisher's exact test because the sample size was too small to allow for Chi-square analysis. All comparisons were based on 2×2 matrices created by combining responses. For example, for each instructional strategy, only current users were considered to be "Users," while all other respondents were considered "Non-Users." Significance was determined using an alpha of 0.01 due to the high number of comparisons. Phi was also calculated to determine the strength of the relationship for the significant results. All calculations were completed using SPSS statistical software.

Limitations

This survey very likely overestimates the actual percentages of chemical engineering faculty members using research-based instructional strategies in their core engineering science courses. We used a second wave of data collection to understand potential survey bias. While the responses we received were statistically similar, the response rate of 20% was still low—although typical for web surveys.[40] In the earlier survey of department chairs (whom we selected to reduce survey bias),[20] 76% of chemical engineering department chairs reported that at least one of their faculty members was using active-learning pedagogies and they estimated that 38% of chemical engineering faculty members (in all undergraduate courses) were using active learning on a regular basis. The use of active learning reported in this survey is significantly higher, suggesting the possibility of a response bias in this study. In addition, one might reasonably suspect that faculty members who are not interested in teaching, or who limit the time they spend on teaching, are unlikely to fill out a survey about their teaching. Looking at the number of attended teaching workshops reported by respondents also suggests that this sample of faculty is particularly committed to improving their teaching quality. Finally, the high levels of awareness and use of many of the research-based instructional strategies reported in this study seem inconsistent with the experience of many of us who routinely conduct faculty development workshops with engineering instructors. For all of these reasons, we caution that the results and analyses reported here are more useful for what they say about a particular subsection of chemical engineering faculty and for the insights they provide about the relative rankings of RBIS awareness and use, information sources, and perceived barriers to adoption.

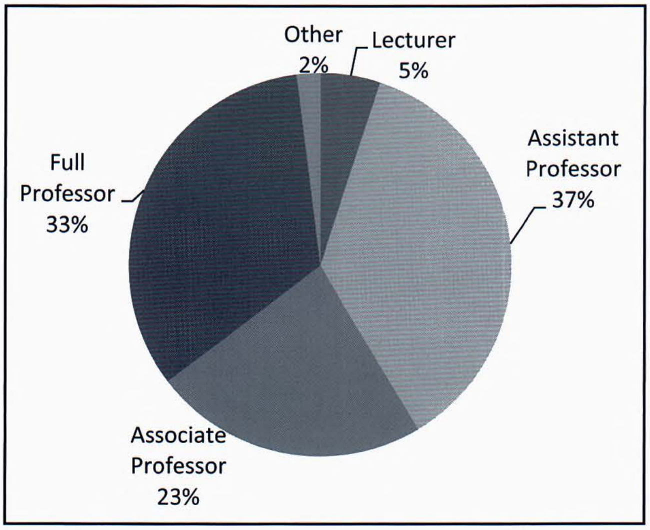

Figure 1. *Respondent rank.*

RESULTS

Characteristics of Respondents

Figures 1-4 illustrate some key characteristics of the survey respondents. Compared to faculty in all engineering disciplines, female faculty are slightly overrepresented among respondents; 20% of respondents were female, as compared to 15% nationally.[41] Compared to faculty members in all engineering disciplines, full professors are underrepresented and assistant professors are overrepresented among our respondents (ASEE reports 45% full professors, 25% associate, 20% assistant, and 10% lecturers among full-time faculty, as compared to Figure 1).

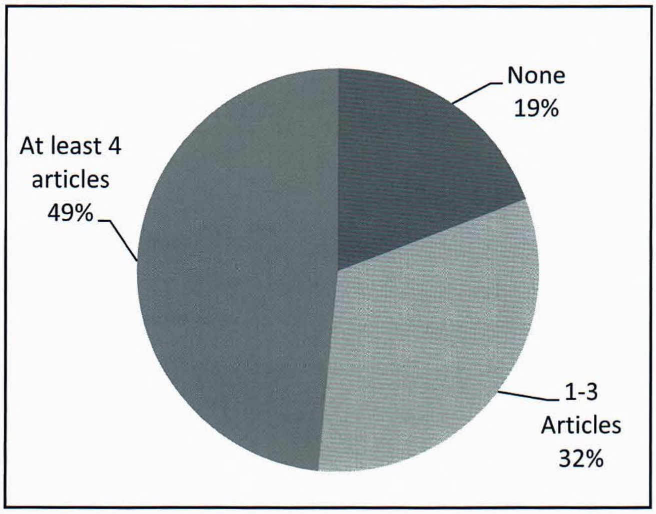

Figure 2. *Respondent technical research publications for past three years.*

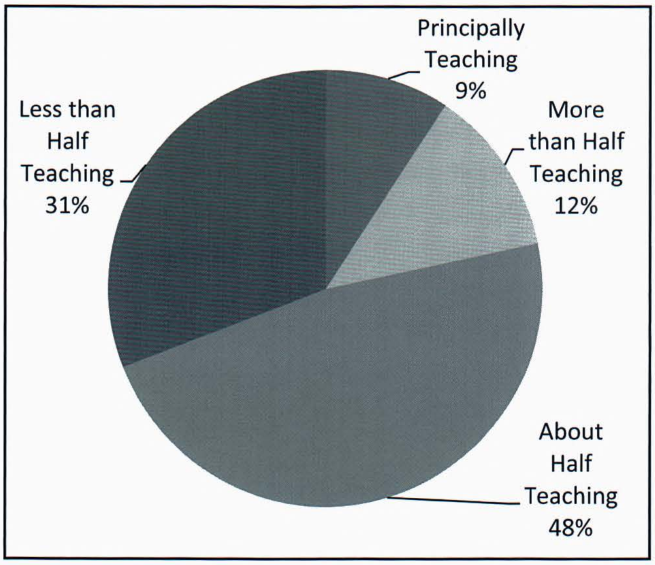

Figure 3. *Respondent job responsibilities with respect to teaching.*

Among respondents, 58 recently taught thermodynamics, 49 recently taught fluid mechanics, and 41 recently taught heat transfer. Their average class size was 48 students, and they had an average of 12.2 years of experience teaching undergraduates.

The majority, 57%, attended one to three workshops on teaching in the past two years. Another 19% attended more than that, but 24% attended none. Eight percent had attended the National Effective Teaching Institute. Approximately half of the respondents (49%) reported discussing teaching with colleagues several times per semester or term. Figures 2-4 provide additional information about respondents' research activity, job responsibilities with respect to teaching, and frequency of teaching discussions with colleagues.

Awareness and Use of RBIS Among ChE Faculty

Table 2 presents faculty members' awareness and use of the 12 research-based instructional strategies, ordered by current use. Results show that chemical engineering faculty members who responded to the survey are generally aware of most of the strategies; all but two are above 80% awareness. Based on these responses, efforts to make faculty aware of these practices have been generally successful. Results also show that adoption trails awareness for every RBIS, and in many cases gaps between awareness and adoption are large. The smallest gaps are 32 percentage points for collaborative learning and 39 percentage points for active learning. These two RBIS take the least amount of preparation time outside of class. The largest gaps are for service learning (75 percentage points), peer instruction (72 percentage points), cooperative learning (69 percentage points), and case-based teaching (67 percentage points). In general, these require more preparation time than active or collaborative learning, so the large gap between awareness and adoption for these strategies is likely influenced by realistic perceptions of required preparation time.

In addition to examining initial adoption rates, we also examined whether faculty who try an innovation continue to use the strategy. The final column in Table 2 is a ratio of current to past users. We see that discontinuation after some initial use is a significant problem. Four RBIS have ratios less than one, which means more faculty have tried and abandoned

TABLE 2
ChE Faculty Awareness, Current Use, and Past Use of RBIS

	Aware	Currently use	Used in past	Ratio current: past users
Collaborative Learning	97%	65%	14%	4.6
Active Learning	99%	60%	21%	2.9
Problem-Based Learning	98%	35%	12%	2.9
Inquiry Learning	96%	31%	21%	1.5
Concept Tests	91%	27%	15%	1.8
Think-Pair-Share	90%	25%	14%	1.8
Cooperative Learning	86%	17%	18%	1.0
Case-Based Teaching	93%	16%	21%	0.8
Peer Instruction	87%	15%	4.0%	3.8
Just-In-Time Teaching	63%	10%	3.1%	3.3
Thinking-Aloud-Paired Problem Solving	64%	6.1%	9.1%	0.7
Service Learning	80%	5.1%	12%	0.4

TABLE 3

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

	Total Respondents	Do not recall	Colleague (word of mouth)	Read article or book about it	Presentation or workshop on my campus	Pres. or workshop at an engineering education conference (*e.g.*, FIE, ASEE)	In-depth workshop of one or more days (*e.g.*, NETI, NSF-sponsored)	Pres. or workshop at my professional society conference (*e.g.*, AIChE)
Collaborative Learning	94	27%	28%	12%	13%	5.3%	7.4%	4.3%
Active Learning	98	20%	19%	12%	18%	8.2%	6.1%	6.1%
Problem-Based Learning	93	31%	19%	15%	11%	4.3%	6.5%	5.4%
Inquiry Learning	90	50%	11%	11%	6.7%	5.6%	6.7%	2.2%
Concept Tests	90	31%	22%	16%	14%	2.2%	4.4%	4.4%
Think-Pair-Share	88	31%	17%	10%	16%	9.1%	4.5%	8.0%
Cooperative Learning	82	38%	23%	11%	13%	4.9%	4.9%	2.4%
Case-Based Teaching	88	53%	14%	11%	3.4%	5.7%	4.5%	4.5%
Peer Instruction	83	41%	14%	12%	14%	6.0%	3.6%	2.4%
Just-In-Time Teaching	63	21%	24%	16%	11%	11%	1.6%	11%
Thinking-Aloud-Paired Problem Solving	63	38%	10%	14%	7.9%	6.3%	11%	9.5%
Service Learning	75	37%	23%	6.7%	17%	2.7%	6.7%	2.7%
Average across all RBIS	N/A	35%	19%	12%	12%	5.9%	5.7%	5.3%

than are currently using service learning, thinking-aloud-paired problem solving, case-based teaching, and cooperative learning. This suggests that significant effort is needed to support faculty in their implementation of these strategies. Most likely faculty will need to be supported in customizing an instructional strategy for their situation. The reasons for discontinuing use of an instructional strategy may also be linked to the reported barriers for adopting innovative strategies, which are discussed in more detail later in this paper.

Demographic Factors That Affect Awareness and Use of RBIS

We examined how gender, rank, research activity, workshop attendance, teaching responsibility, and discussing teaching with colleagues influenced awareness and use of instructional strategies. Given the small sample size and conservative nature of our statistical testing, no differences emerged for awareness and only three significant differences emerged for use. First, faculty who talk with their colleagues about teaching on a regular basis are more likely to use collaborative learning ($p = 0.003$). Second, ChE faculty who attended the National Effective Teaching Institute were more likely to use thinking-aloud-paired problem solving ($p = 0.006$). Third, faculty members who attended any type of multi-day teaching workshop were more likely to use peer instruction ($p = 0.01$). These significant results provide some insight into how faculty members are likely to learn about various instruc-

TABLE 4
How ChE faculty found more information about specific instructional strategies.
This question allowed multiple responses. Percentages are based on number of respondents who selected each strategy.

	Total Respondents	Do not recall	Colleague (word of mouth)	Read article or book about it	Pres. or workshop on my campus	Pres. or workshop at an engineering education conference (*e.g.*, FIE, ASEE)	In-depth workshop of one or more days (*e.g.*, NETI, NSF-sponsored)	Pres. or workshop at my professional society conference (*e.g.*, AIChE)
Collaborative Learning	86	24%	42%	42%	28%	16%	17%	24%
Active Learning	95	12%	49%	52%	39%	19%	19%	26%
Problem-Based Learning	89	26%	37%	44%	17%	16%	18%	22%
Inquiry Learning	89	42%	24%	30%	16%	10%	10%	16%
Concept Tests	86	28%	34%	31%	16%	16%	12%	13%
Think-Pair-Share	88	25%	34%	27%	25%	15%	14%	16%
Cooperative Learning	80	31%	30%	38%	25%	15%	14%	19%
Case-Based Teaching	81	48%	25%	31%	12%	16%	7.4%	11%
Peer Instruction	77	36%	26%	56%	19%	7.8%	9.1%	13%
Just-In-Time Teaching	59	25%	39%	36%	22%	15%	6.8%	14%
Thinking-Aloud-Paired Problem Solving	59	24%	29%	39%	20%	15%	15%	17%
Service Learning	67	48%	28%	22%	19%	12%	9.0%	10%
Average across all RBIS	N/A	31%	33%	37%	22%	14%	13%	17%

tional strategies. The results presented here are consistent in many ways with those found in physics education.[38] In physics, differences between new faculty who tried and did not try RBIS were significantly correlated with attending a multi-day workshop and attending other talks or workshops related to teaching. Thus, there is strong support for the continued use of workshops as important dissemination mechanisms. On the other hand, the physics survey did not find a correlation between knowledge or use of RBIS and frequency of teaching discussions with colleagues. This is likely because conversations about teaching can have a variety of forms, both logistical and pedagogical. More work is needed to more fully understand the types of conversations that can result in improved teaching.

Dissemination Mechanisms For Initial and Follow-up Information About RBIS

Table 3 presents the various ways that faculty initially found out about each of the 12 instructional strategies. For the very first exposure to specific instructional strategies, "do not recall" was the most frequent response (average 35%). Colleagues were the most frequent initial source for all but one of the instructional strategies (thinking-aloud-paired problem solving). The importance of colleagues is emphasized in these results; trusted colleagues can be key in encouraging a faculty member to seek more information about instructional strategies.

Table 4 lists the various ways that faculty members found additional information about research-based instructional strategies. Books and articles were the most popular supplementary sources for most of the 12 instructional strategies; in three cases (concept tests, think-pair-share, and service learning), colleagues were a more frequent ongoing source of information than publications.

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. In fact, the literature emphasizes frequent collegial discussions to help faculty members think through how they might implement instructional strategies, experiment, and improve their approaches over time.[42, 43] That emphasis is consistent with our findings.

Reported Barriers to Broader Adoption of Specific RBIS

Table 5 presents the barriers faculty perceived to adopting each of the 12 instructional strategies. Overwhelmingly, they listed class time and prep time as the major considerations in whether to use instructional strategies. For half of the instructional strategies, class time was a larger concern than prep time (collaborative learning, active learning, think-pair-share, cooperative learning, peer instruction, and thinking-aloud-paired problem solving). For the other half, faculty preparation time before class was more critical (problem-based learning, concept tests, case-based teaching, just-in-time teaching, and service learning). Clearly, efforts to improve adoption rates of new instructional strategies must address these common faculty concerns, which in some cases are actually misconceptions about the strategies. For example, cooperative learning typically requires significant preparation time but need not consume any significant amount of actual class time, suggesting that some faculty concerns stem from a misunderstanding of what is required to implement some of these strategies. A

TABLE 5

Barriers to Adopting Specific Instructional Strategies. This question allowed multiple responses. Percentages are based on number of respondents who selected each strategy.

	Total Respondents	Takes up too much class time to let me cover the syllabus	Too much advanced preparation time required	Lack of evidence to support the efficacy of this instructional strategy	Students would not react positively	My department does not have the resource to support implementation	My department and administration would not value it
Collaborative Learning	66	58%	29%	33%	27%	4.5%	4.5%
Active Learning	74	58%	38%	26%	20%	6.8%	4.1%
Problem-Based Learning	68	44%	53%	29%	21%	4.4%	4.4%
Inquiry Learning	74	46%	46%	34%	22%	4.1%	2.7%
Concept Tests	67	39%	52%	30%	16%	4.5%	4.5%
Think-Pair-Share	64	64%	30%	33%	25%	3.1%	3.1%
Cooperative Learning	58	59%	34%	36%	28%	5.2%	1.7%
Case-Based Teaching	71	44%	63%	39%	17%	2.8%	4.2%
Peer Instruction	73	52%	25%	41%	37%	5.5%	2.7%
Just-In-Time Teaching	58	47%	69%	28%	10%	12%	3.4%
Thinking-Aloud-Paired Problem Solving	50	56%	26%	36%	38%	4.0%	4.0%
Service Learning	64	41%	64%	33%	13%	9.4%	11%
Average across all RBIS	N/A	51%	44%	33%	23%	5.5%	4.2%

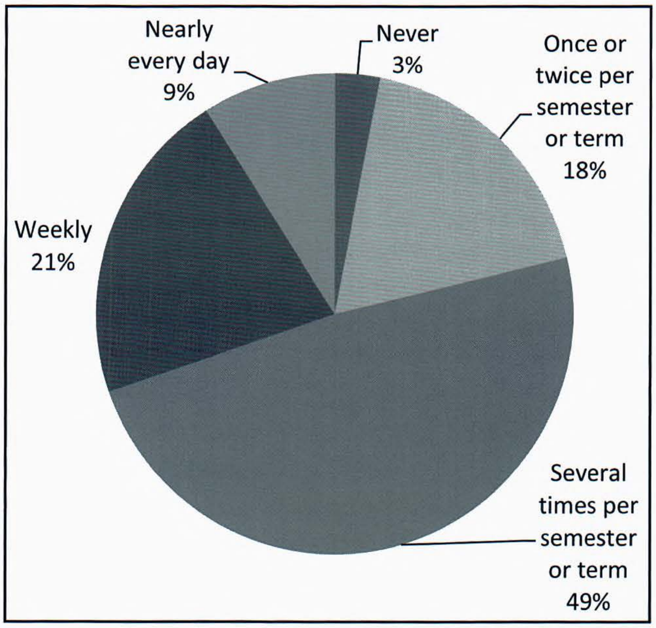

Figure 4. *Frequency of respondent discussions about teaching with colleague.*

secondary concern was that the instructional strategy might not actually improve student outcomes. ChE faculty members were most skeptical about peer instruction, case-based teaching, thinking-aloud-paired problem solving, and cooperative learning. Again, these perceptions are contrary to significant research that supports the use of these strategies, suggesting the need for better awareness of the relevant research by engineering instructors. Some faculty members were also concerned about student reactions to new instructional strategies, particularly for peer instruction and thinking-aloud-paired problem solving, but this concern was not as strong as others overall. Finally, concerns about department resources and value of teaching efforts in promotion and tenure were surprisingly low (average 4.2 and 5.5%), with one notable exception of case-based teaching (11% and 9.4%).

We can conclude that many ChE faculty members do not believe their administration to be one of the most significant barriers hindering use of research-based instructional strategies. They do, however, list time as the primary barrier, and pressures about how to spend one's limited time can be an important indirect influence. Much of the discussion around engineering faculty change includes efficiency arguments, based on the assumption that if an instructional change takes more time than the current approach, then faculty members will not be interested. While time is clearly an important concern, any instructional change, such as adopting a new textbook or digitizing course notes, requires additional time. In some cases, these changes result in efficiency gains in later semesters; in others, they are done because the faculty member believes it is important for student learning. It may be the case that more nuanced arguments around faculty time and responsibilities would better address these concerns.

SUMMARY AND DISCUSSION

Awareness of RBIS among the ChE faculty members who responded to this survey is quite high, in most cases above 80%. Use varies more significantly, from 5-65%. Faculty members identified a number of barriers to adopting these instructional strategies. Time, both preparing and in class with students, was their biggest concern (average 44% and 51% of faculty members). Secondary concerns were lack of evidence for the strategies' effectiveness and student reactions, while concerns about department resources and values were much lower. Few statistically significant differences were identified between faculty respondents who do and do not use specific instructional strategies, but those identified reinforce the importance of teaching workshops and regular discussions with colleagues about teaching. Similarly, most faculty members initially found out about RBIS through conversations with colleagues. In a few cases, colleagues were also the most frequently cited source for more information. Overall, faculty tended to turn to publications to learn more about research-based instructional strategies.

These results lead to several implications for chemical engineering faculty members interested in using research-based instructional strategies. First, they are in good company; 87% of faculty who completed the survey indicated that they currently use at least one of these strategies. While there is reason to believe that this number overestimates actual use, for reasons discussed previously, it is clear that many of these research-based instructional strategies are finding their way into the classroom. Faculty members who are using these or other innovative instructional strategies should take advantage of opportunities to tell their colleagues about what they are doing. One of the findings from this survey is that many faculty members who know about an RBIS first learned about it from a colleague. Unfortunately, collegial conversations about teaching do not take place as often as they should. It is up to everyone involved in engineering education to foster these sorts of discussions. These informal discussions are also opportunities for current users to discuss how they overcame the barriers to implementation, particularly since many users have tried and abandoned RBIS.

Faculty developers and educational researchers should expand their propagation (*i.e.*, dissemination) approaches. The traditional approaches of conference presentations, papers, and other publications are important archival sources for detailed information. More interpersonal approaches were also found to be very influential, however. Beyond isolated workshops, chemical engineering education innovators should be working to develop local and virtual communities of practice to help others learn about, adapt, and improve their instructional approaches. The content of these propagation approaches should address time concerns, particularly incorrect perceptions, including frank discussion about how much time one might expect to spend implementing an RBIS and the trade-offs involved in using class time on more interactive strategies. For example, to what extent is it possible to teach core engineering science topics using these RBIS?

These findings also suggest several opportunities for future work. Use of RBIS varies significantly in ways that are not entirely understandable from the information we collected in the survey. More work is needed to understand how characteristics of the RBIS, the instructor, and the instructional context interact to impact RBIS use. Many faculty members tried some of the RBIS but no longer use them. Again, the reasons are not clear from the data we collected, but the high percentage of faculty members who have discontinued use begs additional investigation. Perhaps most significantly, perceptions of time (both class time and prep time) are an important barrier to the use of RBIS. Identifying ways to deal with this time barrier is clearly important. Finally, perceptions about time demands and equipment needs ,and evidence of effectiveness, were not necessarily consistent with the literature on these RBIS, suggesting the need for additional education efforts to make faculty more aware of the relevant research and the real implementation issues for these various strategies.

ACKNOWLEDGMENTS

This research was supported by the U.S. National Science Foundation through grants 1037671 and 1037724, and while M. Borrego was working for the foundation. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors wish to thank Dr. Margot Vigeant and the Virginia Tech Center for Survey Research for their partnership and assistance on this project.

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