Pedagogical practices and instructional change of physics faculty

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We report on the initial results of a web-based survey of 722 physics faculty in the United States regarding their instructional practices. The survey responses indicate that most faculty report knowing about many physics education research curricula and pedagogies and are interested and motivated to try them in their teaching. However, self-reports of actual classroom practices indicate that the availability of these curricula and pedagogies has not led to fundamental changes in instruction. Faculty report that time is the biggest impediment to implementing more research-based reforms. These results suggest a need for research-based dissemination that accounts for the complexity of instructional change.
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I. INTRODUCTION

Over the past several decades many research studies have been conducted to better understand the teaching and learning of introductory college-level physics.[1,2] This extensive body of research has been used to develop many curricula and pedagogies that have been shown to improve desired outcomes such as problem solving skills, conceptual understanding, and student attitudes.[1,3] Although a great deal of effort has been put into research, development, and dissemination of ways to improve college physics teaching, the impact of these efforts on physics instruction is not well known. Further, there is no clear explanation for why many physics faculty do not use these research-based instructional practices.

In this paper, we report on several aspects of a larger study conducted to better document the current state of college-level physics teaching in the United States and to learn more about when, why, and how physics faculty use research-based practices. Specifically, we focus on two research questions: What pedagogical practices do faculty report using, and why do faculty not adopt more research-based practices?

II. THEORETICAL BACKGROUND

The design of the study was based largely on the results of a smaller pilot study.[4,5] In the pilot study, we interviewed faculty not doing physics education research (PER), who had attributes that made them ideal candidates for implementing research-based strategies. Specifically, they were senior (thus, tenure pressure should not be a factor), they had time to learn about, try, and reflect on multiple methods and they were considered by their peers to be dedicated, thoughtful teachers who genuinely cared about their students. Several themes emerged from the pilot study:

(1) *Many common ideas about why research-based reforms are slow to integrate into mainstream teaching were found to be questionable.* Common explanations for the slow rate of adoption of research-based instruction include that faculty are focused on research and do not care about teaching, faculty are not aware of research-based innovations, and faculty are not convinced of the value of research-based innovations. None of these explanations were supported by our pilot study. Our interviewees were dedicated instructors who knew about many innovations, and for the most part thought that the innovations have value. Yet, they still taught traditionally. Valuing good teaching and the products of physics education research may be necessary for research-based change, but it is not sufficient (see Ref. 4 for a more complete discussion).

(2) *Situational characteristics of an instructor's environment play an important role in the nature of classroom instruction.* Dissemination efforts often assume that if instructors know about and believe in the value of an innovation, they will chose to implement it. However, evidence suggests that actions are a result of both individual and situational characteristics. It appears that many instructors may teach traditionally while holding beliefs that are more consistent with research-based instruction than with traditional instruction. We found evidence that situational characteristics play an important role in this mismatch (for example, an instructor wants to use methods that utilize extensive student-student interaction, but is assigned a classroom with bolted down chairs). One implication is that dissemination efforts based solely on changing faculty beliefs are not likely to be successful. The faculty also need help in identifying and overcoming common situational barriers.[4]

(3) *Faculty often modify research-based instructional strategies*. It appears to be rare for an instructor to take a product from physics education research and implement it as is. Instructors have a tendency to use research-based products to generate ideas as they develop their own approaches to teaching. Sometimes the modifications are minor, but often they are substantial. Additionally, it was clear from our interviews that faculty might misreport the use of some practices. For example, they may report having a highly "interactive" classroom, but upon further probing, it is clear that there is little to no student-student interaction, little to no hands-on activities, and teacher-student interactions with only a small handful of students.[6] Evidence suggests that if modifications are made by faculty to research-based curricula and ideas, then these modifications are most likely to be in the direction of making the innovation more in line with traditional instruction.[5]

Table I. Demographic characteristics of survey respondents by type of institution, academic rank, gender, and semesters of teaching an introductory course.

Type of institution	Academic rank	Gender	Semesters taught
Two-year college 25.8%	Lecturer 7%	Male 83%	1–4 semesters 15%
Four-year college (BA) 35.3%	Assistant professor 20.8%	Female 17%	5–10 semesters 20%
Four-year college with graduate program 38.9%	Associate professor 24.2%		>10 semesters 65%
	Full professor 35.6%		
	Other rank 12.3%		

Based on these interview results, we designed a survey to more fully document and understand what, how, and why research-based innovations are integrated into mainstream physics teaching. Specifically, we included questions to further check the validity of common assumptions about educational change, probed for reasons for discontinuing the use of strategies or failing to implement strategies that included environmental constraints as well as individual characteristics, asked about modifications to research-based strategies, and included questions to determine the extent to which faculty were engaged in specific classroom practices prescribed by the research-based products they claimed to be using.

III. STUDY DESIGN

A web-based survey was developed and administered to a national sample of physics faculty from three types of institutions. The final survey consisted of 61 questions. Demographic information was collected (including years teaching, rank, employment status, gender, and type of institution) as well as information about the courses the faculty member taught (calculus or algebra based, class size, structure of laboratories and recitation, and number of sections). Most of the survey focused on collecting information about the participant's knowledge and the use of 24 specific research-based strategies that have been developed and disseminated in recent years. Finally, participants were asked general questions about their teaching goals and practices. Full details of the survey design and implementation, as well as the complete survey, are reported in Ref. 7.

The survey was administered in Fall 2008 by the American Physical Society Statistical Research Center. Over 2000 faculty at randomly selected institutions were asked to complete the survey. The response rate was 50.3% and yielded 722 usable responses (not usable responses were due to noncompletion, failure to provide informed consent, or failure to meet criteria for inclusion such as having recently taught an introductory course). The demographics of the final sample are provided in Table I. The sample demographics are reasonably consistent with what would be expected in the general population of physics faculty, and thus there is no obvious response bias. Our data also indicate that general interest in teaching innovations did not overly bias the sample. Specifically, the response rate by type of institution was not correlated with stated interest in using more innovations. Although we cannot rule out response bias completely, all indications are that our sample is reasonably representative of the larger population of physics faculty.

IV. WHAT PEDAGOGICAL PRACTICES DO FACULTY REPORT USING?

The first goal of our study was to document the extent to which research-based practices have made their way into mainstream physics teaching. After all, if dissemination efforts are already successful at changing instructional practice, there is no need to further study the issue.

Survey participants were presented with a list of 24 specific research-based instructional strategies and asked about their level of knowledge and use of each strategy. Follow up questions probed the extent to which strategies were modified when used and reasons for discontinuing use. A full reporting of these data is provided in Ref. 7, including data specific to each strategy included in the survey. The results are summarized in the following.

A. Do faculty know about research-based innovations?

- 87% of the respondents reported familiarity with at least one of the 24 strategies.
- Approximately half (49%) of the respondents reported familiarity with more than five of the strategies.
- The strategy that was the best known was Peer Instruction,[8] with 64% of the faculty reporting familiarity.
- Eight of the strategies (Peer Instruction, Physlets,[9,10] Cooperative Group Problem Solving,[11,12] Workshop Physics,[13,14] Just in Time Teaching,[15] Tutorials in Introductory Physics,[16] Interactive Lecture Demonstrations,[17] and Activity Based Physics Tutorials[18]) were familiar to more than 40% of the faculty surveyed.

Although there is room for improvement, our data indicate that dissemination efforts have been reasonably successful in terms of generating faculty awareness of the existence of research-based innovations. The majority of faculty are aware of at least some research-based innovations.

B. Do faculty use research-based innovations?

Nearly half (48%) of the respondents reported that they currently use at least one strategy. At first glance, this finding appears to be a very positive result as it indicates that not only are faculty aware of innovations, but many faculty are willing to try these innovations. However, some caution is in order. There is evidence in our data which indicates that when faculty report using a strategy, actual classroom behavior is often inconsistent with that strategy.

As an example, consider Peer Instruction. Peer Instruction was the most widely known and the most highly used strategy (29% of instructors). Among those instructors who reported using Peer Instruction, 41% indicated that they "used

Table II. Percentage of respondents who indicated that they used Peer Instruction who also self-report using specific classroom practices consistent with Peer Instruction.

	Percentage of respondents
Students discuss ideas in small groups (multiple times every class)	27
Students solve/discuss qualitative/conceptual problem (multiple times every class)	27
Whole class voting (multiple times every class)	38
Conceptual questions (used on all tests)	64

some of the ideas, but made significant modifications" and 6% indicated that they were "not familiar enough with the developer's description" to indicate the extent to which they modified the strategy in their own use. Nearly half of all the respondents indicating that they used Peer Instruction also indicated that they did not use it in a way that is consistent with the method developed by the researchers and demonstrated to be effective.

It is possible to modify a strategy while still maintaining or even improving its effectiveness. It is unreasonable to assume that any method can be developed and used in the same exact form in every environment. However, if extensive modifications are being made, then the type and extent of those modifications need to be considered because there is a possibility that one or more components essential to student learning may be eliminated. In the survey, we asked a series of questions that allow us to make some inferences about the actual classroom behaviors of the faculty, which report the use of Peer Instruction.

Peer Instruction has several important components,[8,19] which include the use of traditional lecture interspersed by the posing of conceptual questions, student-student discussion about their ideas, whole class voting, and conceptual questions on exams. Table II shows the percentage of instructors who reported being current users of Peer Instruction and who also reported specific classroom behaviors.

Notice that the majority of Peer Instruction "users" are not incorporating many of the nontraditional components of Peer Instruction that the developers argue are important to the success of the method.[8,19] These faculty appear to be using instructional strategies that may be related to or inspired by Peer Instruction, but that have not been rigorously tested for efficacy. Therefore, although the faculty report using many of the products of physics education research, caution should be taken when interpreting this result because it does not necessarily mean that their classroom practices are consistent with what the research literature would suggest is necessary for improved student learning. The extent to which research-based innovations are modified and the kinds of modifications made appear to be an important aspect to consider when evaluating the impact of dissemination efforts.

C. What general classroom practices do faculty report using?

There is no one way to teach physics that is effective for all students and faculty in all situations. It is reasonable to expect the faculty to use ideas from research and adapt them to their own personalities and local environments. However, some characteristics of teaching are known to be more effective than others. In particular, there are several general characteristics common to most of the research-based strategies. They involve student-student interactions, place importance on conceptual understanding, encourage higher level thinking over rote learning, and encourage active learning over passive learning. Additionally, low performance on measures of student learning are consistently associated with passive classroom activities such as traditional lecturing.[20,21] We asked a series of questions about general classroom practices to gauge the extent to which faculty are engaging in activities commonly associated with both positive and negative student learning outcomes.

Respondents were asked "In the 'lecture portion' of your introductory course, please estimate the percentage of class time spent on student activities, questions, and discussion." Results are presented in Fig. 1 and show a strong tendency to not include many of these types of activities as a significant portion of the course.

We are not aware of any research indicating the optimal amount of time spent on student activities, questions, and discussions. Redish[1] presented data to support his claim that full interactive strategies (such as workshop physics) can produce substantially better FCI gains than moderate active-engagement strategies (such as Tutorials in Introductory Physics or Cooperative Group Problem Solving). Based on timing suggested by Mazur,[8] we estimate that a moderate active-engagement strategy such as Peer Instruction would result in approximately 20% of class time spent on student activities, questions, and discussion.

Respondents were then asked "In thinking about the LAST time you taught an introductory algebra- or calculus-based course… How frequently did you use these strategies in the lecture portion of the course?" A list of strategies then followed with multiple choice answers. The percent of faculty reporting each level of use is shown in Table III.

Only three of the methods listed do not require student involvement. These are focused primarily on the actions of the instructor (traditional lecture, instructor solves/discusses quantitative/mathematical problem, and instructor solves/discusses qualitative/conceptual problem). Strikingly, the top three most used methods are these three methods, which allow students to be relatively passive. The method that gives students the most autonomy (students design experiments/activities) is the least used.

Research has consistently demonstrated that students learn more when they are active and engaged. However, it appears that most instruction is still primarily such that the instructor is active while students are allowed to be passive.

We also asked about practices on tests and quizzes. The percent of faculty indicating each level of use is reported in Table IV. Not surprisingly, the most common element on exams is the well defined quantitative problem, which often lends itself to a plug-n-chug solution approach. Questions that are open-ended and/or require higher level thinking skills are less likely to be used. Conceptual questions, advocated by physics education research, appear to be used by a reasonable percentage of the faculty. If the goal of physics instruction is to help students become better problem solvers and to develop higher level thinking skills, then the result that exams often fail to assess these skills is discouraging.

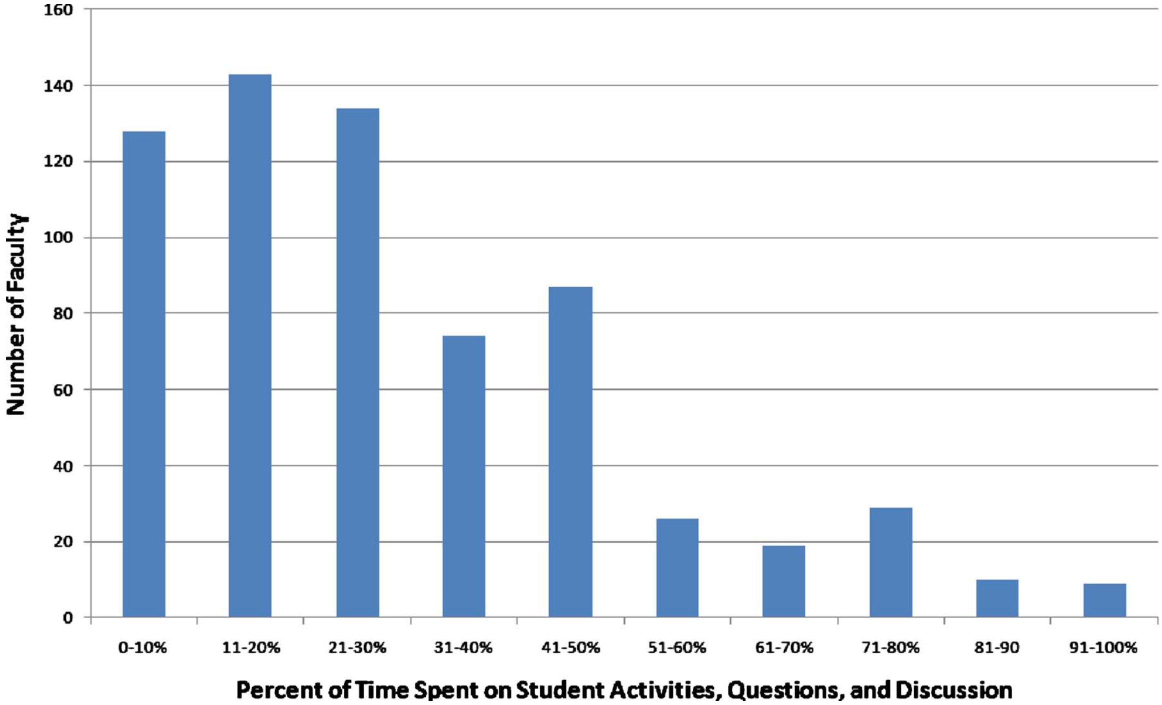

Fig. 1. Percentage of class time spent on student activities, questions, and discussion as reported by faculty.

D. Discussion

It appears that current dissemination efforts are successful at "getting the word out" and motivating faculty to try innovations. Most faculty report knowing about research-based innovations. Additionally, many faculty attempt to use these innovations in their classrooms. However, our survey data indicate that despite knowing about innovations and being willing to use ideas from the innovations in their teaching, to a large extent, actual teaching practices are still traditional and not consistent with practices demonstrated to improve student learning outcomes.

V. WHY DO FACULTY NOT ADOPT MORE RESEARCH-BASED IDEAS?

As discussed in Sec. I, very little is known or understood about how or why physics faculty come to use ideas from PER despite extensive research, development, and dissemination efforts over the past several decades. In this section, we explore why research ideas have not had a greater impact on mainstream teaching.

A. Are faculty interested in change?

One hypothesis is that faculty are not interested in changing. However, when we asked participants if they were inter-

Table III. Faculty reports of the use of specific classroom practices.

	Never	Once or twice	Several times	Weekly	For nearly every class	Multiple times every class
Instructor solves/discusses quantitative/mathematical problem	1%	2%	9%	23%	43%	24%
Traditional lecture	4	4	6	16	48	22
Instructor solves/discusses quantitative/mathematical problem	1	3	8	20	45	22
Whole class voting	22	9	18	14	18	19
Students solve/discuss qualitative/conceptual problem	11	9	15	23	28	14
Students discuss ideas in small groups	25	14	12	19	17	13
Students required to work together	25	10	16	22	15	12
Students solve/discuss quantitative/mathematical problem	12	10	18	25	25	10
Students design experiments/activities	63	19	10	7	1	0

Table IV. Faculty reports of the use of specific types of questions and problems on tests.

	Never used on tests	Used occasionally on tests	Used frequently on tests	Used on all tests
Well-defined quantitative problems	2%	6%	23%	69%
Conceptual questions	7	22	26	45
Questions that require students to explain their reasoning	16	30	24	30
Multiple choice questions	34	21	17	29
Novel problems	22	45	23	10
Open-ended quantitative problems	59	30	8	3

ested in using more research-based strategies, 70% responded yes (see Fig. 2). This percentage is somewhat lower for faculty at institutions offering a graduate degree in physics, but still includes a majority of faculty.

Additionally, we found that when the faculty were aware of an innovation, they often tried it. For example, 68% of all faculty who reported being aware of Peer Instruction had tried it. Likewise, faculty with knowledge of a strategy reported being a user or former user at least 50% of the time for the following strategies: Ranking tasks (66%), cooperative group problem solving (61%), interactive lecture demonstrations (52%), and physlets (50%). Thus, it appears that the faculty are generally interested in change.

B. Are faculty motivated to change?

1. External motivation

92% of the faculty report that their department is either very encouraging or somewhat encouraging about efforts to improve instruction. On the surface, this percentage is a very positive result. However, when those who responded that they were interested in using more research-based strategies were asked why they did not do so, a significant number gave a response indicative of not having solid support from their department (see the following for a more complete discussion of the reasons faculty list for not using more research-based strategies). The reason for this discrepancy is unclear. One possible explanation is that departments may be more encouraging in a theoretical sense (that is, they say they want to improve teaching which leads faculty to report feeling encouraged to do so) and less encouraging in practical ways (for example, they fail to provide time and/or resources necessary to make changes). This discrepancy warrants further study.

2. Internal motivation

To gain some understanding of the extent to which the faculty may be internally motivated to change instruction, we asked respondents to rate the importance of the instructional goals of problem solving, conceptual understanding, and attitude and appreciation of physics. These are instructional goals commonly mentioned by the developers of research-based instructional strategies. We then asked them to rate the extent to which they were satisfied their instruction was reaching each goal. The results are shown in Table V.

Traditionally, physics instruction has focused on problem solving. One of the major themes of PER has been to demonstrate that students can learn to solve difficult and complicated problems while still maintaining only a weak understanding of the basic underlying concepts.[22,23] Therefore, most of the research-based products have a strong focus on the development of conceptual understanding. The finding that faculty rate the goals of problem solving and conceptual understanding approximately the same is a positive result and indicates that faculty are likely to be receptive to most of the kinds of innovations promoted by physics education researchers.

Underlying many of the innovations is the belief that students' attitudes are important and interplay with other factors to effect success on other course goals (such as problem solving and conceptual understanding). Faculty often did not view attitudes and appreciation of physics as being a very important goal (though only 3% rated it as not at all important). This finding indicates that faculty may not be receptive to research-based curriculum that focus on student attitudes and that when using research-based curriculum they may be susceptible to modifying or disregarding components that focus on student attitudes.

Although faculty appear to generally share goals that are consistent with research-based reforms, they appear to be

Table V. Percentage of faculty indicating the importance of instruction goals and their satisfaction with reaching goals.

	Respondents rating goal as very important	Respondents who rated the goal as very important who are extremely or somewhat satisfied with extent to which students are meeting the goal.
Problem solving	90%	73%
Conceptual understanding	92	70
Attitudes and appreciation	51	54.9

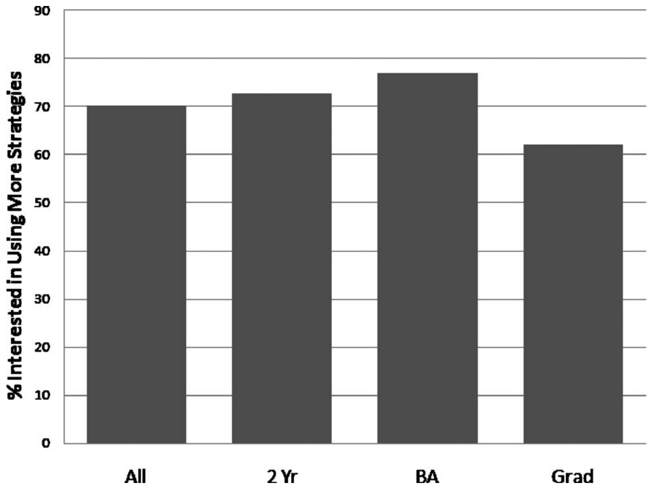

Fig. 2. Percentage of faculty answering yes to the question "Are you interested in using more of the kinds of instructional strategies addressed in the previous questions?"

generally satisfied that they are reaching these goals. If someone is satisfied with the extent to which they are reaching a goal, then they are presumably less likely to be interested in changing what they are doing. Thus, the high level of satisfaction that the faculty report indicates they might not be completely open to innovation. However, despite reporting high levels of satisfaction, the faculty also report high levels of willingness to try more research-based innovations. The reasons for this apparent discrepancy are unclear.

C. What reasons do faculty give for not using more research-based innovations?

For the 70% of respondents who said that they were interested in using more research-based instructional strategies, they were given a text box and asked "What prevents you from using more of these strategies?" 91.6% of the respondents wrote in the text box. A summary of the responses as categorized by the authors is given in Table VI. By far the most common reason mentioned was a lack of time (mentioned by 52.7% of those answering the question). In some cases, it was clear from the responses that the respondent was referring to the extra time required to learn about a strategy and then effectively implement the changes. For example, comments included "Time constraints in researching different techniques and integrating them into the course" (a two-year college instructor); "Time for investigating the different systems and then implementing them into my particular course" (a BA instructor); and "A lack of time to get acquainted with the methods and develop the course" (a graduate instructor).

In other cases, though, the respondent did not explain what the time was for, often writing the single word "time" in the response box. In both cases, some respondents would elaborate about heavy teaching, research, or administrative duties that compete for their time.

The second most common reason for not using more research-based strategies was a lack of familiarity with them. For example, comments included "Lack of knowledge about any of them" (a two-year college instructor); "Ignorance. I have never heard of most of these strategies" (a BA instructor); and "I have never heard of any of them" (a graduate instructor).

Table VI. Categorization of responses to the question "What prevents you from using more research-based instructional strategies?" The percentage of respondents providing an open-ended response indicating each reason is reported.

Time	
Time to learn about and implement changes	28.6%
Time (not elaborated)	24.1
Lack of knowledge about/access to RBIS	
Lack of familiarity with many RBIS	22.4
Lack of access to RBIS	3.1
Weaknesses of RBIS	
Difficult to cover material (uses too much class time)	8.0
Not convinced of benefit	6.6
Requires too much instructor time to use	2.4
Student resistance (real or perceived)	2.1
Lack of ready-to-use materials	0.7
Lack of motivation to adopt RBIS (other than TIME)	
I don't follow one method, but adapt pieces of many to fit my teaching style.	6.1
Nothing	1.9
Inertia	1.2
Lack of fit with department or institution	
Cost to implement (e.g., laboratory equipment, additional staff)	4.0
Need to coordinate changes with colleagues	3.8
Lack of appropriate classroom space/class scheduling	3.7
Cost (not elaborated)	2.6
Colleagues would not approve	2.1
Cost for students (e.g., books, clickers)	0.7
Unclear	
Unclear response	4.7

Other concerns mentioned by much smaller percentages of the faculty were grouped into categories of weaknesses of strategy, lack of motivation to adopt strategy, and lack of fit with department or institution. We were unable to understand and categorize 4.7% of the responses.

D. Discussion

Whether or not a known innovation is adopted depends on factors unique to an individual (including beliefs, motivations, and knowledge) as well as environmental factors. Survey results indicate that to a large extent the characteristics of individual faculty necessary for change are present. Most faculty report that they are interested in and motivated to improve their instruction. Faculty often report some environmental conditions that are not supportive of change; in particular, the lack of time to learn about and implement changes. "Time" was the number one reason the faculty gave for not using more research-based strategies. Although the lack of time is a real hindrance, we hesitate to conclude that with more time, instructors would implement more research-based strategies. There are likely more complicated reasons underlying these instructors' belief that lack of time prevents them from using more strategies. For example, faculty often spend much time preparing detailed lecture notes and presentations even to the detriment of other job responsibilities.[24] Instructors will exert significant effort developing and changing instruction, but that effort may or may not be in the direction of research-based changes. To what extent is "time" really the issue? If the faculty are feeling frustrated, confused, or unsure about implementing a strategy, they may have a tendency to say "I don't have the time." More follow-up is needed to understand the reasons for the perceived lack of time. We are investigating this issue more extensively with individual interviews and hope to provide more insights in the future.

VI. CONCLUSION

Dissemination efforts in physics education have been successful in some respects. Although improvements could be made, faculty are often aware of research-based innovations and are willing to try them. Two areas appear to be limiting substantial and sustained changes in classroom practice. Faculty usually modify strategies, often modifying out essential components (such as student-student interaction). Also, faculty report work environments that do not allow them to invest the time required to make a major instructional change.

Over the past several decades, physics education research has matured substantially. Gone are the days of "I tried this in my classroom and it seemed to work." Curriculum development is now frequently based on extensive teaching/learning theory along with rigorous testing and evaluation. However, the field has not generally taken this research-based approach to dissemination. The approach to dissemination is typically unarticulated and untested. For example, in a review of articles on efforts to disseminate new instructional strategies, Henderson *et al.*[25] found that a significant number of studies do not report a specific change strategy or offer evidence of success or failure of change efforts.

Typically, dissemination involves informing the faculty of the research-based innovation, convincing them of the need for the innovation, and providing them with new curricular materials. Although this model is intuitive, it is not based on data and has not been shown to be effective. The results of our study indicate that this dissemination model may successfully increase awareness of both the innovation and the need for the innovation and may also encourage faculty to try the innovation. However, there is a gap between a faculty member deciding to try something and the innovation being successfully integrated into their instruction. The typical dissemination model of developing and distributing materials assumes that once a faculty member is convinced to try something that the innovation has been successfully disseminated. However, this assumption is not the case because faculty often significantly modify and/or discontinue the use of an innovation. Although the inform/convince/distribute strategy is successful at generating initial knowledge and interest in change, it has not resulted in major changes in actual classroom practice. A model that accounts for the complexity of real classroom change is needed.

Based on our results, this model should address the high level of modifications currently being made as well as external constraints faculty face when attempting to integrate research-based strategies. Promoting change in instructional practices is complicated and poorly understood. It would benefit from the same careful research-based focus that has been given to the development of effective curriculum and pedagogies.

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[1]E. F. Redish, *Teaching Physics with the Physics Suite* (Wiley, Hoboken, NJ, 2003).

[2]R. J. Beichner, in *Getting Started in Physics Education Research*, edited by Charles Henderson and Kathleen A. Harper (American Association of Physics Teachers, College Park, MD, 2009).

[3]L. C. McDermott and E. F. Redish, "Resource Letter: PER-1: Physics education research," Am. J. Phys. **67** (9), 755–767 (1999).

[4]C. Henderson and M. Dancy, "Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics," Phys. Rev. ST Phys. Educ. Res. **3** (2), 020102 (2007).

[5]C. Henderson and M. Dancy, "Physics faculty and educational researchers: Divergent expectations as barriers to the diffusion of innovations," Am. J. Phys. **76** (1), 79–91 (2008).

[6]C. Henderson and M. Dancy, "When one instructor's interactive classroom activity is another's lecture: Communication difficulties between faculty and educational researchers," talk at the American Association of Physics Teachers Winter Meeting, Albuquerque, NM, 2005.

[7]C. Henderson and M. Dancy, Phys. Rev. ST Phys. Educ. Res. **5** (2), 020107 (2009).

[8]E. Mazur, *Peer Instruction: A User's Manual* (Prentice-Hall, Upper Saddle River, NJ, 1997).

[9]W. Christian and M. Belloni, *Physlets: Teaching Physics with Interactive Curricular Material* (Prentice-Hall, Upper Saddle River, NJ, 2001).

[10]W. Christian and M. Belloni, *Physlet Physics: Interactive Illustrations, Explorations, and Problems for Introductory Physics* (Pearson Education, Upper Saddle River, NJ, 2004).

[11]P. Heller and M. Hollabaugh, "Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups," Am. J. Phys. **60**, 637–645 (1992).

[12]P. Heller, R. Keith, and S. Anderson, "Teaching problem solving through cooperative grouping. Part 1: Groups versus individual problem solving," Am. J. Phys. **60**, 627–636 (1992).

[13]P. W. Laws, "Calculus-based physics without lectures," Phys. Today **44**(12), 24–31 (1991).

[14]P. W. Laws, *Workshop Physics Activity Guide* (Wiley, New York, 1997).

[15]G. M. Novak, E. T. Patterson, A. D. Gavrin, and W. Christian, *Just-in-Time Teaching: Blending Active Learning with Web Technology* (Prentice-Hall, Upper Saddle River, NJ, 1999).

[16]L. McDermott and P. S. Shaffer, *Tutorials in Introductory Physics* (Prentice-Hall, Upper Saddle River, NJ, 2002).

[17]D. R. Sokoloff and R. K. Thornton, "Using interactive lecture demonstrations to create an active learning environment," Phys. Teach. **35** (6), 340–342 (1997).

[18]E. F. Redish, *Activity Based Physics Tutorials* (Wiley, New York, 2004).

[19]C. H. Crouch and E. Mazur, "Peer instruction: Ten years of experience and results," Am. J. Phys. **69**, 970–977 (2001).

[20]J. Handelsman, D. Ebert-May, R. Beichner, P. Bruns, A. Chang, R.

DeHaan, J. Gentile, S. Lauffer, J. Stewart, S. M. Tilghman, and W. B. Wood, "EDUCATION: Scientific teaching," Science **304** (5670), 521–522 (2004).
[21] R. R. Hake, "Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," Am. J. Phys. **66**, 64–74 (1998).
[22] F. Reif, "Millikan lecture 1994: Understanding and teaching important scientific thought processes," Am. J. Phys. **63**, 17–32 (1995).
[23] A. Van Heuvelen, "Learning to think like a physicist: A review of research-based instructional strategies," Am. J. Phys. **59**, 891–897 (1991).
[24] R. Boice, *Advice for New Faculty Members* (Allyn and Bacon, Needham Heights, MA, 2000).
[25] C. Henderson, A. Beach, and N. Finkelstein, in *Transitions, Transformations and Transgressions in Learning and Education*, edited by Päivi Tynjälä, Marja Leena Stenström, and Marjatta Saarnivaara (in review).