Barriers to the use of research-based instructional strategies: The influence of both individual and situational characteristics

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Many proven research-based instructional strategies have been developed for introductory college-level physics. Significant efforts to disseminate these strategies have focused on convincing individual instructors to give up their traditional practices in favor of particular research-based practices. Yet evidence suggests that the findings of educational research are, at best, only marginally incorporated into typical introductory physics courses. In this paper we present partial results of an interview study designed to generate new ideas about why proven strategies are slow to integrate in mainstream instruction. Specifically we describe the results of open-ended interviews with five physics instructors who represent likely users of educational research. We found that these instructors have conceptions about teaching and learning that are more compatible with educational research than with their self-described instructional practices. Instructors often blamed this discrepancy on situational factors that favor traditional instruction. A theoretical model is introduced to explain these findings.

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I. INTRODUCTION

In recent decades, physics education research (PER) has produced numerous research-based curricular packages and instructional strategies.[1] These products have been highly disseminated through journal articles, workshops and presentations at national and regional meetings, departmental colloquia, for-profit publishing companies, and even a new-faculty workshop attended by approximately one-fourth of the new physics faculty in the United States.[2] However, despite these great efforts, geared mostly toward the introductory sequence of university physics, there is no evidence that the products of PER have been incorporated significantly into the average introductory course.[3] In addition, many PER practitioners believe that most physics instructors continue to use traditional teaching practices and that dissemination of PER products is an important unsolved problem.[3–6] Since high-quality research and development is valuable only if it is actually used, serious investigation is needed into why the proven products of PER frequently do not diffuse into mainstream physics teaching.

Dissemination efforts often aim to convince instructors that their transmissionist learning theories (i.e., that students are "empty vessels" that they can "pour" knowledge into) are incomplete, tell them about better learning theories (i.e., various forms of constructivism) and instructional strategies based on these theories, and convince them that their students will learn more if they adopt these new strategies.[7–10] These efforts appear to be based on the assumption that instructors teach traditionally for one or more of the following reasons related to instructor personal characteristics: (1) instructors have traditional conceptions about teaching and learning,[7,8,11,12] (2) instructors are satisfied with their traditional instruction,[3,11,13,14] or (3) instructors are not aware of any alternatives to traditional instruction.[9,15] The lack of substantial change resulting from these dissemination efforts suggest that some or all of these assumptions are incorrect and/or that there are additional significant barriers to change that need to be addressed.

In an effort to examine these issues, we interviewed physics faculty about their instructional practices, conceptions about teaching and learning, and experiences with educational innovation. Our analysis of these interviews indicates that many common assumptions are insufficient at explaining the slow rate of adoption and that more attention should be given to circumstances beyond individual faculty. Elsewhere we present data suggesting that these faculty agreed with PER researchers on many of the problems with traditional instruction (such as the belief that students do not get much from a traditional lecture) and were all aware of a variety of research-based alternatives.[16] We also identified ways that PER researchers might work more effectively with non-PER faculty in efforts to promote instructional change at the individual faculty level.[16] In this paper we focus on the discrepancy between instructors' stated conceptions and their self-described instructional practices as well as the situational factors that impede instructional changes that could reduce this discrepancy. We use the term "conception" quite broadly to include all internal thoughts that are potentially linked to outward actions. This is consistent with the way the term is used by others,[17] and includes beliefs, attitudes, goals, values, and other similar aspects of an individual instructor's cognition.

II. INTERVIEW SAMPLE

Semistructured, exploratory interviews were conducted with six tenured physics faculty from four different institutions (one small liberal arts college, two regional universities, and one major research university) who teach introduc-

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TABLE I. Main categories of practices.

	Practices consistent with traditional instruction	Practices consistent with alternative instruction
P1. Interactivity	One-sided discourse, passive students	Conversation, active students
P2. Instructional decisions	Made by teacher	Shared by teacher and students
P3. Knowledge source	Students receive expert knowledge	Students develop own knowledge
P4. Student success	Success measured against preset standards	Success measured by individual improvement
P5. Learning mode	Competitive or individualistic learning modes	Cooperative learning modes
P6. Motivation	External motivators	Internal motivators
P7. Assessment	Knowledge-based assessment	Process-based assessment
P8. Content	Explicit teaching of only physics facts and principles	Explicit teaching of learning, thinking, and problem-solving skills in addition to physics content
P9. Instructional design	Knowledge-driven instruction based on understanding of the structure of physics	Student-driven instruction based on understanding of student learning within the discipline of physics
P10. Problem solving	Formulaic problem solving: Problems assigned to students are well defined and similar to problems students have previously seen	Creative problem solving: Problems assigned to students are novel to solver and may have unknown or open-ended solutions

tory level physics courses. These faculty had no formal connections with the physics education research community and were purposefully chosen. We targeted faculty we believed to have characteristics representative of likely adopters of PER-based instructional strategies. Each had a reputation for being a particularly thoughtful and reflective teacher in introductory level physics. As senior faculty, they have had time over their careers to think about their teaching and try new things. Additionally, because of their senior status, worries about tenure should not impact their willingness to incorporate new ideas. If, as is commonly stated, the goal of the physics education reform movement is to create a critical mass of instructors using reformed pedagogical approaches, this type of instructor may be expected to form the core of that critical mass. We were interested in the views and experiences of faculty representing this ideal group.

Each interview lasted over one hour and contained questions about instructional goals, current and past instructional practices, attempts to change practices, and familiarity with educational research. The general questions of each interview were the same but the exact form of each interview was allowed to adjust based on the circumstances of each interviewee. All but one of the interviews were audio recorded and transcribed for later analysis. The remaining interviewee did not grant us permission to audio record. However, the interviewer did take notes and wrote down an extensive summary of the interview immediately after its completion. Because of a lack of verbatim data, the results of this interview are not presented here, yet appear to be consistent with the analysis below.

III. CONCEPTIONS VS PRACTICES

We developed an analysis tool describing a range of possible conceptions and practices related to the teaching and learning of physics. The main categories of this framework along with a brief description of each category are shown in Tables I and II. Details of the framework and its development can be found in Ref. 18 The sections below describe how this framework was used to analyze the five transcribed interviews and present results from this analysis.

A. Practices

The analysis consisted of two main phases. The first phase involved reading the interview transcript and collecting quotes that supported or refuted particular conceptions or practices. These quotes were then placed in a table based on the categories of the framework. As an example, Table III shows the evidence gathered from Gary's (all names are pseudonyms) interview related to the interactivity dimension of instructional practices. Notice that quotes are collected for each of the subcategories. A given piece of text could be used multiple times and was placed in all relevant categories.

Once all references in the transcript were collected, each category was considered in summary and labeled according to our perception of the strength of the practice or conception. These labels were not based on any automatic counting of comments but rather on our assessment of the actual level of practice or conception based on the quality and nature of actual comments.

In some cases there was no direct statement in the interview to support or refute a particular practice. In such cases

TABLE II. Main categories of conceptions.

	Conceptions consistent with traditional instruction	Conceptions consistent with alternative instruction
C1. Learning view	Transmissionist	Constructivist
C2. Expertise	Involves the accumulation of factual information	Involves qualitative changes in thinking
C3. Knowledge view	Positivist: Knowledge is absolute	Post positivist: Knowledge is socially constructed
C4. Nature of physics	A quantitative discipline	A quantitative and qualitative discipline.
C5. Role of school	Sort and certify students for roles in the workplace and society	Develop independent thinkers and enrich students' personal lives
C6. Students	All students learn the same way and only some are capable of learning physics	Different students learn differently, but all are capable of learning physics
C7. Teacher role	Teacher should teach	Teacher should guide
C8. Diversity	Students should adapt to the teacher	Teacher should adapt to the students
C9. Desired outcomes	Students can quickly and accurately solve familiar problems within the context of physics	Students develop an understanding of physics concepts as well as the skills to apply these concepts to new situations
C10. Scientific literacy	Informed citizen who can appreciate scientific methods and use science as developed by scientists in everyday and professional decision-making	Informed citizen who can apply scientific methods to problems that interest them as well as critique science methods and results

an inference was made if it seemed reasonable. For example, in the case of Gary, he never discussed what the students were physically doing during class so the category was labeled as "no evidence" for him. This does not mean that the particular practice or conception was not present, just that it did not specifically come up in the interview. Based on the rest of Gary's interview, in which it was apparent that his classroom practice was generally traditional, and the assumption that traditional practices are less likely to be mentioned than alternative practices (people are more likely to mention that which is different or unique and assume knowledge of that which is normal), it is likely that his students were physically passive throughout the class period.

In the second phase of analysis we used the interview evidence to assign an indicator of the instructor's fit with each category according to the scheme described in Table IV. After the verbal comments were organized as described above, the result was considered as a whole and a label was applied. Taken together, Gary's practice related to the "interactivity" dimension was rated as being traditional (T). Although there were a few mentions of practices that might be considered alternative, taken in context these practices were only superficially alternative. For example, although he reports asking for general student questions, he indicates that students usually ask none, and while he reports occasionally stepping down from lecturing, he indicates that this time is replaced with students answering highly structured worksheet exercises focused on the teacher's ideas. There is one place in the interview where it can be inferred that he focuses on student ideas via the use of multiple-choice questions, perhaps similar to peer instruction.[13]

Each author independently completed both phases of the analysis for each individual instructor. In approximately 80% of cases we agreed on the ratings. In the instances where we initially disagreed, the difference was never more than one level apart (e.g., one author rated ST and another M). All differences were resolved through discussion. This empirical evidence suggests that the "uncertainty" of our measurements can be considered to be one level.

Based on each of the practice category ratings for an individual instructor, an overall practice rating was made. For example, Gary was rated as traditional on seven categories and as semitraditional on three categories. In addition to simply having more categories in the traditional ranking, a review of the statements made by Gary indicates that, even when Gary was toward the alternative side, he was often superficially so (as described above). Thus, he received an overall rating of traditional. There was no disagreement between the authors on the overall rankings of any interviewee.

A summary of the analysis results for all five instructors is given in Tables V.

B. Conceptions

Conceptions about teaching and learning were assigned in the same way as practices. As an example, see Table VI, which shows the evidence gathered from Gary's interview related to the teacher role category of conceptions.

Taken together, Gary's conceptions related to teacher role were rated as being mixed. He exhibits both traditional and alternative conceptions in almost all of the subcategories.

TABLE III. Example of analysis. Evidence collected from Gary's interview related to the interactivity category of instructional practices (P1). An assessment of the strength of available evidence is provided at the beginning of each cell. Numbers in parentheses indicate line numbers in the interview. Thus, a variety of well-separated numbers in a particular category shows that evidence was collected from multiple parts of the interview, while only one number, or a set of nearby numbers, suggests that evidence was collected from only one part of the interview.

	One-sided discourse, passive students	Conversation, active students	
Subcategory description	Evidence	Evidence	Subcategory description
Teacher does most of the talking. Few students talk (Lecture)	Strong evidence "There are times when I'll go in and pretty much lecture and I'm the one doing the talking, I'm up in front." (8) "I pretty much know what I want to say. But then I'm also trying to follow the sequence of the notes and so sometimes I will get far away from the notes and I'll have to come back." (14) "I kinda do this routinely, everyday in class, see if there's questions on the homework I give back, see if there's questions on the homework that's due that day, open up for any general questions, usually don't get too much." (18) In an effort to keep the story flowing, he will often pause briefly to let students think rather than have students respond after he asks a question. (212) "So going to the board and explaining what my reasoning process is going through. Without interruptions from them." (217)	Weak evidence "Then I had a written exercise I distributed and we spent the rest of the time which was probably a good 2/3 of the period working on the exercise with me going around coaching them." (30) He later indicates that the use of such exercises in class is rare. (41)	Students and teacher share talking. Most students talk (conversation).
Most discourse is teacher-student	Strong evidence "Open up for any general questions, usually don't get too much." (18) "I ask lots of rhetorical questions." (189) In an effort to keep the story flowing, he will often pause briefly to let students think rather than have students respond after he asks a question (212)	No evidence	Significant student-student discourse.
Discourse focuses on teacher's ideas (e.g., students ask clarifying questions and teacher asks rhetorical and/or closed questions)	Strong evidence "I kinda do this routinely, everyday in class, see if there's questions on the homework I give back, see if there's questions on the homework that's due that day, open up for any general questions, usually don't get too much." (18) "I decided then that I'd better give them a 15 min introduction to springs so I essentially told them what they would have done if they had been in the lab. (inaudible) a quick runthrough." (30) "The exercises are different from the end of chapter problems, usually, in that they're usually one long sequence of steps to solve a problem." (45) I: "And so you've really, you've broken this [problem statement] down into individual steps for them so that you take them through it." G: "Yes" (87) "I ask lots of rhetorical questions." (189)	Weak evidence "I'll pose a problem or question and say, all right now here are three possible answers, now vote. I usually do this when I am almost sure they are going to vote wrong so I can clear up a misconception." (194)	Discourse focuses on students' ideas (e.g., students and teacher ask and answer conceptual and/or open-ended questions).

While he sees himself as the content expert who decides what is important to learn and how students are likely to learn it best, he also sees himself as a guide to students as they struggle to understand the material. In Gary's ideal world, there would not be rigid semester boundaries and he could work with students at their own pace.

Based on each of the conception category ratings for an individual instructor, an overall conception rating was made. For example, Gary was rated as traditional on one category, as semitraditional on one category, as mixed on three categories, as semialternative on three categories, and as not classifiable on two categories. Using this information along with

TABLE III. (*Continued.*)

	One-sided discourse, passive students	Conversation, active students	
Subcategory description	Evidence	Evidence	Subcategory description
Students write teacher's ideas (i.e., take notes)	Strong evidence Although he has students work individually sometimes, they are working on very structured exercises. "Then I had a written exercise I distributed and we spent the rest of the time, which was probably a good 2/3 of the period working on the exercise with me going around coaching them." (30) "The exercises are different from the end of chapter problems, usually, in that they're usually one long sequence of steps to solve a problem." (45) I: "And so you've really, you've broken this [problem statement] down into individual steps for them so that you take them through it." G: "Yes." (87)	No evidence	Students write their own ideas (beyond copying notes)
Students are physically passive	No evidence	No evidence	Students are physically active (e.g., interacting with equipment or materials)

a consideration of the relative strength of his comments in each category, we rated him as having overall mixed conceptions. As with the practices ratings, each researcher independently rated the instructors, comparisons were made, and discrepancies were resolved.

A summary of the analysis results for all five instructors is given in Table VII.

C. Conceptions more alternative than practices

A comparison between Tables V and VII shows that every instructor was rated as more alternative on the conceptions scale than on the practices scale. Thus, we conclude that these instructors had instructional conceptions that were more alternative than their instructional practices. All of the instructors were rated as either semialternative or mixed on the conceptions scale. None exhibited conceptions purely or even mostly consistent with traditional instruction. In contrast, three of the instructors had a majority of self-described teaching activities consistent with traditional practices. The other two instructors (Mary and Harry) described a mix between traditional and alternative teaching practices. However, both Mary and Harry started out their teaching careers using more traditional methods. As discussed later, Mary describes always having semialternative conceptions that she was able to implement only recently due to changes in her teaching situation. Harry, on the other hand, describes starting out his instructional career with very traditional concep-

TABLE IV. Categorization scheme used to classify main categories of practices and conceptions for each instructor.

Label	Category	Description
T	Traditional	Practices and conceptions are overwhelmingly traditional
ST	Semitraditional	Evidence of some significant alternative practices and conceptions along with predominantly traditional practices and conceptions
M	Mixed	Significant evidence of both traditional and alternative practices and conceptions
SA	Semialternative	Evidence of some significant traditional practices and conceptions along with predominantly alternative practices and conceptions
A	Alternative	Practices and conceptions are overwhelmingly alternative
NC	Not classifiable	There is not enough evidence to make a rating

TABLE V. Rating of interviewees' self-described instructional practices on main categories of practices.

	Harry	Gary	Mary	Barry	Terry
1. Interactivity	T ST M **SA** A NC	**T** ST M SA A NC	T ST M **SA** A NC	T **ST** M SA A NC	T **ST** M SA A NC
2. Instructional decisions	**T** ST M SA A NC	**T** ST M SA A NC	T **ST** M SA A NC	**T** ST M SA A NC	**T** ST M SA A NC
3. Knowledge source	T **ST** M SA A NC	**T** ST M SA A NC	T ST **M** SA A NC	**T** ST M SA A NC	T **ST** M SA A NC
4. Student success	**T** ST M SA A NC	**T** ST M SA A NC	**T** ST M SA A NC	**T** ST M SA A NC	T **ST** M SA A NC
5. Learning mode	T ST **M** SA A NC	**T** ST M SA A NC	T ST M **SA** A NC	T **ST** M SA A NC	**T** ST M SA A NC
6. Motivation	**T** ST M SA A NC	T **ST** M SA A NC	T ST M SA A **NC**	**T** ST M SA A NC	T **ST** M SA A NC
7. Assessment	T ST M **SA** A NC	T **ST** M SA A NC	T ST M **SA** A NC	T **ST** M SA A NC	T ST M **SA** A NC
8. Content	T ST **M** SA A NC	**T** ST M SA A NC	T ST **M** SA A NC	T **ST** M SA A NC	T ST **M** SA A NC
9. Instructional design	T ST M **SA** A NC	T **ST** M SA A NC	T ST M **SA** A NC	T **ST** M SA A NC	T ST M **SA** A NC
10. Problem solving	T **ST** M SA A NC	**T** ST M SA A NC	T ST **M** SA A NC	**T** ST M SA A NC	T **ST** M SA A NC
Overall	T ST **M** SA A NC	**T** ST M SA A NC	T ST **M** SA A NC	T **ST** M SA A NC	T **ST** M SA A NC

tions and practices. "I assumed that if I could deliver the perfect lecture I would get the perfect response. And that very much meant my work in class was chalk and talk." His conceptions changed partly due to personal reflection and partly due to his exposure to educational research. His practices changed along with his conceptions, to a certain extent, but, as described in the next section, were constrained by situational factors.

As a specific example of this discrepancy between conceptions and practices, consider the area of problem solving. This is represented in the practice categories of assessment (P7), content (P8), and problem solving (P10) and in the conception categories of expertise (C2) and desired outcomes (C9). All of the instructors expressed the conception that one of their main desired outcomes was developing students' problem solving and thinking skills. They also all expressed the conception that the best evidence of problem solving skills (as well as an understanding of physics principles) is a student's ability to solve novel problems. In practice, however, most of the instructors explicitly taught only physics content and wrote exams that contained problems very similar (or identical) to ones students had already seen.

This can be seen in Gary's interview. When he was asked to describe his main goal for the course, he said: "I think I'm teaching problem solving. And I'm probably teaching in the broader sense, I'm teaching problem solving in life as much as physics, physics is kind of incidental, almost." Later, when he was asked how he knew when his students had developed their problem-solving skills he responded: "If they are encountering a new application they're showing problem-solving skills in physics, other than just repeating a solution they've done before, they've seen me do before." Although Gary felt that the development of students' problem-solving abilities was a very important outcome, and that problem-solving ability is measured by being able to solve novel problems, he admitted that most of his exam questions come directly from a study guide he provides. Thus, he did not test the students' ability to problem-solve in the way he (and the educational research community) believed valid.

When probed on this issue, Gary recognized the inconsistency between his conception and practice and commented: "I think the primary reason is that I'm probably guilty of dumbing down the course recently…I know that most of my students are not learning problem solving. If I change the situation they think it's a whole new problem." So, while Gary believed that the ability to solve novel problems was an important course goal, he also believed (and had experiential evidence to support the belief) that his instructional practices, which did not involve students solving many novel problems, did not result in most students reaching this goal.

This pattern of self-described practices being more traditional than self-described conceptions has also been found in other studies of college faculty.[19,20] As we listened to these faculty, and tried to understand their experiences with innovation, we found that many barriers to reform often reside outside the instructor's direct control.

IV. SELF-IDENTIFIED SITUATIONAL BARRIERS TO REFORM

If the conceptions of these instructors are generally more alternative than their practices, what is preventing them from bringing their practice more in line with their conceptions? Part of this inconsistency between conceptions and practices arises, no doubt, from the difficulties involved in translating abstract ideas and goals into concrete instructional actions. PER, however, provides many examples of how this can be accomplished. For example, in the case of Gary described above, there are many proven instructional strategies available that help students become better at attacking novel (to them) problems (e.g., Refs. 21–24). As described elsewhere, these interviewees exhibited knowledge about the general findings of PER and many of the associated instructional strategies.[16] Thus, a lack of awareness of PER-based strategies does not seem to fully explain these inconsistencies.

When conducting the analysis of instructor practices and conceptions described above, we noticed that instructors were often aware of inconsistencies between their conceptions (e.g., students learn best when allowed to develop ideas for themselves) and self-reported practice (e.g., lectures where the instructor develops ideas for the students). They generally attribute these inconsistencies to situational constraints and barriers.

TABLE VI. Example of analysis (C7). Evidence collected from Gary's interview related to the teacher role category of conceptions. An assessment of the strength of available evidence is provided at the beginning of each cell. Numbers in parentheses indicate line numbers in the interview. Thus, a variety of well-separated numbers in a particular category shows that evidence was collected from multiple parts of the interview, while only one number, or a set of nearby numbers, suggests that evidence was collected from only one part of the interview.

	Teacher should teach	Teacher should guide	
Subcategory description	Evidence	Evidence	Subcategory description
Determine what and how students should learn	Strong evidence "The exercise is asking them questions to get them more actively involved and it kinda highlights the things I want them to understand (inaudible) and some things I just kinda leave out." (53) Exercises have small steps that guide students. (87 and 163) "The bad part is I get further away from my notes, I'll go off, I'll begin improvising a bit because I pretty much know what I want to say. But then I'm also trying to follow the sequence of the notes and so sometimes I will get far away from the notes and I'll have to come back." (11)	Strong evidence "…working on the exercise with me going around coaching them. And that's really what I'm working toward." (32) "So the quiz is then intended to make sure that they're ready for the class and if I can do that then I think I can spend more time in, with them working at their tables." (76) "I was trying to point it out as I was coaching the student." (136) "The exercises are also intended to have me virtually there in the sense that I were coaching them and asking them questions step by step." (161) "I guess it was while I was here, maybe 10 years ago …I developed a system of testing where I had five different levels of questions… and they [each student] got different ones depending on where they were…I thought, well, this is the answer to take them where they are and build them up and not expect them to do things that they are just not capable of." (324) "I think in a perfect world…they [students] wouldn't have a time deadline of 15 weeks, we'd work it out together." (352) "I'm having a little trouble switching over… from a lecture style to a more do it yourself style." (523)	Provide a resource to students as they decide what to learn and at what pace
Determine the pace of the class	Strong evidence "[Having students respond to questions] just seems to bog things down And I kind of feel like I can keep the story flowing a little bit better if I just pause and let them think. So, it's a compromise, I still have control and I don't really know what's going on in their heads." (214) "So going to the board and explaining what my reasoning process is going through. Without interruptions from them." (218)	Weak evidence "Ideally I would like to lecture only when I'm asking them questions or doing demonstrations, and telling very little." (216)	Lead discussions among students

For example, Harry described his conception of the value of having students work in groups.

"I like the idea of dividing the class into smaller subgroups and work independently on projects…I want to try to turn the lecture into sort of a minitutorial at various points. I think that has promise. In all the times in the past when I've done that, when I've gotten students to organize into small groups and talk to each other, at least they're talking physics to each other. You can see that there is some understanding going on, some transfer of knowledge taking place."

Although Harry believed it was beneficial for students to work in groups and had positive experiences with this method, he did not use the method in his practice as often as he would like: "Because I was racing to get through the curriculum I had to pretty much drop [the group work]."

Harry repeatedly talks in his interview about feeling pressure to present material, rather than use interactive methods, due to a need to cover content. He also talked about students'

TABLE VI. (*Continued.*)

Teacher should teach		Teacher should guide	
Subcategory description	Evidence	Evidence	Subcategory description
Present knowledge, be an expert	Strong evidence "The exercise is asking them questions to get them more actively involved and it kinda highlights the things I want them to understand (inaudible) and some things I just kinda leave out." (53) "At points through there I gave them the answer so that they wouldn't get the wrong answer to this and that would affect everything else they did." (167) "I try to emphasize that they've got to memorize definitions, a definition is something you don't have to understand, you don't derive it, we all agree to it. Political agreement. There are some equations which the book doesn't derive, or you need calculus to really do it well, so they have to accept that on faith." (237)	Strong evidence "I've kind of struggled to figure out how to help them." (259) Different tests for different students system. (324) "More times than not I'm kind of disappointed with what happens in the classroom. Its generally because I haven't done that good a job at teaching." (513) "Yeah, when I first started teaching I was worried about not making a mistake. I mean that doesn't bother me now." (542)	Develop situations where students can learn
Judge students performance	Strong evidence "I'm going to work on a system where to get an A you've got to do certain things." (267) "We always need to give them [students] tasks and tell them if they've done it the way we want them to." (355) "Now I wouldn't mind a system where everybody gets an A if they work long enough." (613) "I tell them specifically, remind them that grades are negotiable if they think I made a mistake on the grading, tell me." (706)	Moderate evidence "Everybody needs to be tested in a general sense in order to learn. I mean you've got to try new things and see if you can do something." (362) "I feel it is my responsibility to show them exactly where they went wrong." (384)	Provide feedback
		Weak evidence "I hope that I convey a little excitement, valuing knowledge and the learning process." (695)	Motivate students

TABLE VII. Rating of interviewees' instructional conceptions on main categories of conceptions.

	Harry	Gary	Mary	Barry	Terry
(1) Learning theory	T ST M **SA** A NC	T ST **M** SA A NC	T ST M **SA** A NC	T ST **M** SA A NC	T ST **M** SA A NC
(2) Expertise	T ST M SA **A** NC	T ST M **SA** A NC	T ST M SA **A** NC	T ST M SA **A** NC	T ST M SA **A** NC
(3) Knowledge view	T **ST** M SA A NC	**T** ST M SA A NC	T ST **M** SA A NC	**T** ST M SA A NC	**T** ST M SA A NC
(4) Nature of physics	T ST M SA **A** NC	T ST M SA A **NC**	T ST M SA **A** NC	T ST M SA A **NC**	T ST M SA **A** NC
(5) Role of school	T ST **M** SA A NC	T ST M **SA** A NC	T ST M SA A **NC**	T ST **M** SA A NC	T ST M **SA** A NC
(6) Students	T ST **M** SA A NC	T **ST** M SA A NC	T ST M **SA** A NC	T ST **M** SA A NC	T ST M **SA** A NC
(7) Teacher role	T ST M **SA** A NC	T ST **M** SA A NC	T ST **M** SA A NC	T **ST** M SA A NC	T ST M **SA** A NC
(8) Diversity	T ST M **SA** A NC	T ST **M** SA A NC	T ST M SA **A** NC	T ST **M** SA A NC	T ST M SA **A** NC
(9) Desired outcomes	T ST M SA **A** NC	T ST M **SA** A NC	T ST M SA **A** NC	T ST **M** SA A NC	T ST M SA **A** NC
(10) Scientific literacy	T ST M SA A **NC**	T ST M SA A **NC**	T ST **M** SA A NC	T ST M SA A **NC**	T **ST** M SA A NC
Overall	T ST M **SA** A NC	T ST **M** SA A NC	T ST M **SA** A NC	T ST **M** SA A NC	T ST M **SA** A NC

resistance to working in groups and a lecture room with fixed seating that is "not ideally configured for group work."

Thus, we examined each interview to identify self-described situational factors that influenced an instructor's choice of either traditional or alternative practices. We found that most of the situational factors were described in terms of constraints preventing use of alternative instructional strategies. For example, most instructors talked about wanting to integrate more "heads-on" activities, such as those supported by research, into their classroom. However, they did not believe they could cover the large content required if they spent time on these activities. This situational constraint, of course, does not prevent faculty from implementing heads-on activities. It does, however, raise the barrier to such implementation and, thus, decreases the number of faculty implementers.

A summary of the most salient barriers identified by our interviewees is given below.

1. Student attitudes toward school. (Mentioned by all five instructors.) Instructors often cite poor student study skills or work ethics as limiting their ability to fully enact their instructional conceptions.

"They [students] need to take a little more responsibility for their education…There's a little bit of an attitude that you're only here for the degree. I just want my job. I don't care. I just want to get out of here. You know, I'd rather work 40 hours per week so I can have my cell phone and my satellite TV."—Mary

2. Expectations of content coverage. (Mentioned by four instructors.) Instructors may forgo research-based methods that are geared toward deep understanding if they feel they must cover a lot of material. Likewise, they may change their instruction if this expectation is diminished.

"Whenever you do something like that [have students work together in class] you're not very efficient about covering material."—Barry

3. Lack of instructor time. (Mentioned by four instructors.) Instructors are sometimes too busy with large teaching loads and/or research responsibilities to have the time to learn about and integrate new techniques.

"It kinda depends on how lazy I am, I will try to write those [test questions that students have not seen before] as much as possible. If I'm in a hurry then I will tend to pick more from the old questions."—Gary

4. Departmental norms. (Mentioned by four instructors.) If other members of the department are integrating research-based methods it is easier for instructors to do so as well. It is much more difficult if traditional methods are the norm and there are no local role models to follow or be supportive.

"I am more comfortable with being more interactive and, of course, since we've started [a grant-supported departmental reform]. I'm much more comfortable having them do group work in class, and feeling that that's a valid way of spending time in class. And I'm more comfortable asking conceptual-type questions instead of just problem-solving-type questions because you know there's that extra validation of having a group of people doing this and that it is a grant and it's a research project."—Mary

5. Student resistance. (Mentioned by three instructors.) Students often do not support research-based methods. In particular, they do not like to interact with each other and are often not prepared to think independently.

"I find students very reluctant to talk to each other during class."—Terry

6. Class size and room layout. (Mentioned by three instructors.) Many of the instructors indicated that they worked in departments where they were expected to teach large numbers of students in lecture halls with seats bolted to the floor. They indicated that these characteristics made it harder to use many research-based methods that focus on interactivity, cooperative learning, and formative assessment.

"Given the fact that it is a huge class…I don't know where these students are at…. There's very little chance for one-on-one dialogue…. If I had a smaller class where I know the individuals then I could try to tailor an explanation. But that's a luxury that we don't have."—Harry

7. Time structure. (Mentioned by two instructors.) Semesters are of a fixed length of time and do not allow for individual differences in learning needs. Also, since students are taking other courses, the time they have available for one course is limited.

"I think time students can spend on a particular course is one thing [that prevents me from reaching my goals]. Time for every student in the course to reach the same level because they all start at different levels and they would all take different amounts of time to get to whatever level you want to call understanding."—Terry

It is important to note that our data only illuminate self-reported situational barriers. It is likely that there are other situational barriers that are not noticeable because they are so pervasive. For example, the process of grading commands considerable time and attention in most classrooms, and the requirement that an instructor give a final grade to each student must therefore significantly affect instruction. However, because the practice of giving grades is so pervasive and generally unquestioned, most instructors probably have not considered how this situational requirement affects their practice. Situational barriers to alternative instruction are likely only noticed by instructors when they attempt to move out of the traditional mode.

These results indicate that dissemination activities should place more emphasis on understanding the local environment in which instructors teach and how that environment impacts their ability and inclination to be innovative. Most faculty work in institutions where structures have been set up to work well with traditional instruction. Thus, there are many situational barriers to instructional innovations.

A. A toy model

In some traditional physics fields, toy models are used to simplify complex systems by highlighting dominant objects

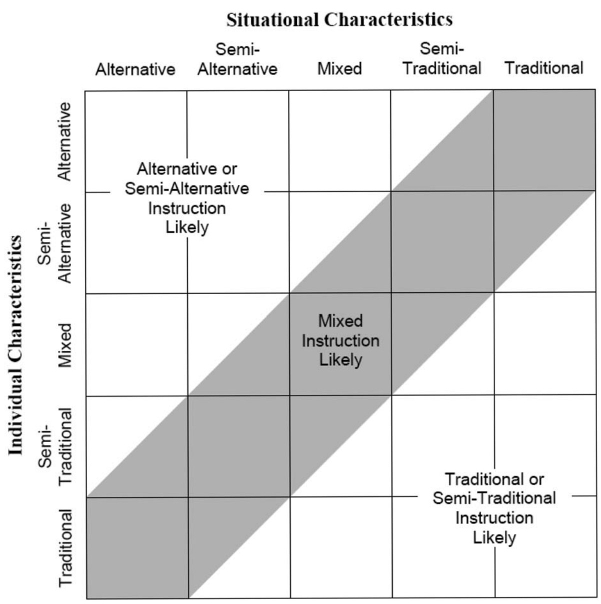

FIG. 1. Toy model for predicting behavior based on individual and situational characteristics.

or mechanisms. In this section we describe a preliminary toy model that describes how individual and situational characteristics relate to instructional practices.

The finding of inconsistencies between conceptions and practice described in the previous sections should not be particularly surprising. Sociologists[25,26] and educational researchers[17,27] have long been aware that conceptions are generally a poor predictor of practice. Based on a theoretical model developed to understand the discrepancies between stated attitudes and behaviors related to racial discrimination,[25] we propose a similar toy model for understanding these instructors' inconsistencies (Fig. 1). In this model, individual characteristics consist of an instructor's conceptions (i.e., beliefs, values, knowledge, etc.) about actual or possible instructional practices. Situational characteristics consist of all aspects outside of the individual instructor that impact or are impacted by the instructors' instructional practices. All of the barriers described in the previous section are situational characteristics, but situational characteristics may also include other things, such as availability of instructional resources, institutional reward system, and disciplinary expectations. According to the model, practice is consistent with conceptions when situational variables support the practice but may be inconsistent when situational variables are in opposition to a particular practice. For example, Gary has conceptions (i.e., individual characteristics) that were classified earlier as a roughly even mixture of alternative and traditional. Given that his practice is predominantly traditional, the model predicts the existence of the incompatible traditional situational characteristics described above.

Other studies of college science faculty[28,29] and nonscience faculty[19,20] agree with this model and suggest that situational factors have a substantial influence on instructional choices. The problem for advocates of reformed teaching, however, is that, although this influence can be in the direction of research-based instruction, it is typically in the direction of traditional instruction. In fact, Mary was the only one of the five interviewees to describe situational characteristics that helped her align her practice more closely with her conceptions, and this was only recently due to changes in the department.

B. Situational change changing practice

If our toy model (Fig. 1) is correct, when situational characteristics become less supportive of traditional instruction and/or more supportive of alternative instruction, then instructors with alternative personal characteristics should become more alternative in their practice. We found evidence of this in our interview with Mary, who, as we mentioned previously, had recently made significant changes in her teaching. Mary indicated that she had always held semialternative conceptions and did not indicate that her conceptions had significantly changed, nor did she indicate that she was only recently aware of the problems with traditional practice. However, she did indicate that she was better able to follow through with her conceptions when the situational variables changed. She described her changes in instruction as being precipitated by situational changes, rather than changes in personal conceptions.

"I would say that it's not just one thing. There've got to be at least three things. It was the release of time so that I had more flexibility in how to cover a lesser amount of material more in depth. Two that there is a group here doing it. And three that I was exposed to more research on how [cooperative learning] works."—Mary

More specifically, as quoted above, Mary identified an increase in confidence and comfort level about implementing reformed instruction when "departmental norms" changed due to a new program undertaken in her department. She found herself in a situation where she was not alone in the reform effort and this helped her to succeed. Likewise, she identified reductions in "expectations of content coverage" as improving her ability to teach in a manner more consistent with her conceptions.

"The fact that we cut out a lot of the material that we need to cover. Because before, I'd think gee if I don't cover fluids and the next instructor is expecting it I'm really crippling these students, handicapping them. But as a whole department we said OK, it's all right for us to cut this material out and spend the time on what you feel is necessary to go more in depth on…. And so the pace was so much quicker that to take a whole class period and potentially have them be a little floundering with group work was just so big of a risk. You know I would have them do some, but it was much more focused and shorter periods of time and I was still much more tentative about how many of them I ended up doing."—Mary

In Mary's case she was able, at least in part, to bring her practices more in line with her conceptions and was able to articulate some of the situational factors that promoted this shift. Her case supports our model and indicates significant importance of situational factors in the change process.

V. DISCUSSION

The five non-PER instructors we interviewed have characteristics that should make them ideal consumers of educational research. However, they indicate only modest influence of this research on their teaching practices. Specifically, they all (a) recognized aspects of their teaching that needed improvement and were seeking ideas for change; (b) described putting considerable time and effort into their teaching; (c) had conceptions about teaching and learning that were more consistent with research-supported strategies than with traditional instruction; (d) were familiar with many results and methods from educational research and generally respected these results; and (e) had access to curricular materials based on educational research.

Often it is hypothesized that instructors' strong traditional conceptions about teaching and learning are the dominant factor in their resistance to implementing research-based curricula.[7,8,11,12] These instructors, however, had conceptions that were more consistent with research than their practices. Other studies suggest similar disjunctions between conception and practice.[19,20] In fact, Samuelowicz and Bain[30] refer to this as "one of the mysteries of higher education—the disjunction between the stated aims (promotion of critical thinking) and educational practice (unimaginative coverage of content and testing of factual recall)" of college faculty (p. 110).

Although our study indicates that many common beliefs about slow adoption rates provide an inadequate explanation, our results and theoretical model do offer explanatory insights. Our interviewees all held mixed or semialternative conceptions. Thus, the toy model (Fig. 1) predicts alternative instruction if the instructors are in a setting where the situational characteristics are mixed or semialternative. As discussed earlier, we saw evidence of such a change in Mary's instructional practices when her situational variables became more alternative.

The research community has focused a majority of its dissemination efforts on moving instructors' individual tendencies to become more alternative. This emphasis can be seen, for example, in the model of educational reform promoted by the National Science Foundation's course curriculum and laboratory improvement program.[31] In such dissemination, the focus is on bringing research-based materials and strategies to faculty who will then, it is hoped, implement these products. There is an implicit assumption that faculty only need expertise in the reform in order to bring about innovation. Rarely does standard dissemination focus on the situational constraints facing faculty or on ways to work with faculty, administrators, and society to overcome these constraints. It appears that this is a significant shortcoming to standard dissemination efforts.

According to the toy model presented earlier, while instructor conceptions do play an important role, they do not appear to be the dominant resistive factor. Figure 2 shows that instructors like the ones we interviewed seem to be clustered, as indicated, somewhere between mixed and semialternative on the individual characteristics scale, and somewhere between traditional and semitraditional on the situational variable scale. Thus, there are two basic strategies that one can take to change instruction from traditional to alternative. The first is to focus on individuals, as is common in many dissemination strategies. As we can see from Fig. 2, changing instructor conceptions (line A) from mixed or semialternative to strongly alternative is unlikely to lead to significant changes in practice. They already have many of the necessary conceptions. What they need is help overcoming the barriers that make it difficult for them to bring consistency between their conceptions and their practice. Thus, the second basic strategy would be to attempt to change the situational variables (line B). In fact, as Fig. 2 shows, even a change in the situation to "mixed" could lead to significant changes in practice. A move to situations that begin to favor alternative practices would likely have an even larger impact. Of course, the strongest change strategy would be to focus simultaneously on individual and situational variables (line C).

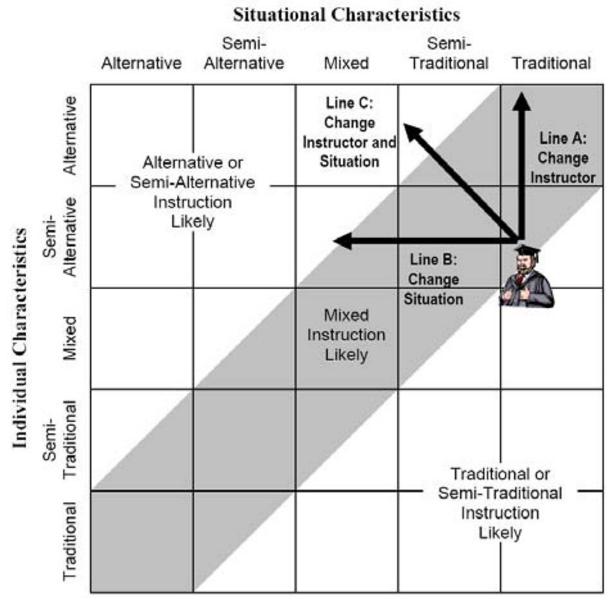

FIG. 2. (Color) Examination of change strategies using the toy model.

Thus, in addition to working on doing a better job in the focus on individual characteristics,[16] we suggest that some of the emphasis be placed on attempting to understand, classify, and change the situational characteristics that appear to play an important role in inhibiting changes in instructor practice. This is not a particularly novel idea and has been suggested as important in both K–12[32] and college settings.[9,33] Yet we note that, while some reformers may mention these situational variables, consideration of the strongly traditional situational factors rarely figure prominently into reform plans.

In the following we raise two questions that cannot be ignored by those interested in sustained and large-scale research-based reforms.

A. Why are the situational barriers there?

Do these criticisms of current teaching practice and suggested changes sound familiar?

"Turn to almost any modern [physics] text. Chapter 1 in a typical one will deal with measurement. (Why, oh why, must we always begin that way?) Somewhat further on there comes a dreary discussion of vector forces, probably beginning with a definition of terms, and then going on for eight or more pages to deal with resultants, components, force parallelograms, and all the rest. (Just how close to the interests of a modern adolescent is this sort of material anyway?)." (Ref. 34, p. 157.)

"Two general ideas have governed the thinking of teachers of both physics and chemistry in the past. These ideas are the mastery of the subject matter of the field as such and the disciplinary value of the subject expressed in terms of training in scientific method.…The workers in the field of physics have been especially in need of some stimulus which would center attention upon the needs of the learner rather than upon the mere structure of the subject matter involved in the instruction." (Ref. 35, pp. 246–248.)

"[Physics] courses are too mathematical and too problematical.…The purpose of problems in our general course is to help clarify physical principles. Yet we have let the solving of problems become an end it itself." (Ref. 36, p. 96.)

"The chronological method which begins with the experience of the learner and develops from that the proper modes of scientific treatment is often called the 'psychological' method in distinction from the logical method of the expert or specialist. The apparent loss of time involved is more than made up for by the superior understanding and vital interest secured. What the pupil learns he at least understands." (Ref. 37, pp. 220–221)

These quotes express a number of common ideas in the current rhetoric of the science education research community; specifically, that physics instruction should be more relevant to the student, that it should be organized around the learner's needs rather than the content, that too much emphasis is placed on mathematical problem solving, and that learner-centered instruction results in more genuine learning. Unfortunately, none of these quotes is recent, ranging in origination from 1916 to 1940. The "modern" text in the first quote referred to texts from the 1930s. Yet the description is just as accurate today as it was 65 years ago.

Why is it that physics instruction is still full of the same inadequacies that were identified nearly a century ago? As the above quotes demonstrate, both the problems and solutions were known. Additionally, the calls for change were coming from respected and theoretically influential entities such as the National Society for the Study of Education in the second quote above.[35]

Over the last century enormous efforts have gone into further clarifying problems with traditional instruction and developing proven solutions. Consider that today there are thousands of self-identified science education researchers[38] and that, since its creation in 1950, the Education and Human Resources Division of NSF alone has directed over $20 billion[39] toward the improvement of science education. The results of all this time and money are widely disseminated in numerous journals, conference venues, listserves, workshops, books, etc. Yet, we are still making the same critiques and calling for the same changes, in a more detailed and eloquent way perhaps, but fundamentally the same.

It appears that identifying problems, demonstrating solutions, and sharing this knowledge, are not enough to bring about the sorts of fundamental change generally supported in the rhetoric of the research community. Our findings and theoretical model predict that genuine reform will not occur if there are situational factors working against the reforms. It is important that the research community do more than develop good ideas, we must also put effort into identifying and understanding the structures that do not support implementation of the good ideas. Historical evidence[40] suggests that educational practice is highly influenced by educational policy and that policy is put into place by those with the power and influence. As Sheila Tobias recently wrote:

"Physics education reform has been focusing largely on classroom-based innovation rather than on the more political and institutional conditions required for long-lasting change. There appears to be a presumption at work among reformers that innovation inevitably leads to change. But anyone who has been seriously engaged in the propagation of innovation or in the wholesale alteration of departmental offerings knows that it is often the exogenous variables that get in the way of real reform, perhaps because they appear to be out of our control." (Ref. 33, p. 103.)

It is important that the educational research community begin to unravel the nature of these political and institutional structures that influence the landscape of educational change. Once we better understand what the barriers are, and why they are in place, we will be in a much better position to overcome them.

B. How can the situational barriers be overcome?

If many important barriers to the use of research-based instruction are situational, then it is important for dissemination efforts geared toward individual instructors to acknowledge these barriers and help instructors find ways to overcome them. The first step is to simply acknowledge the reality of the difficulties instructors will face. Too often, reforms are presented as if they can easily be incorporated.

For example, we often hear the call to encourage more group interactions during class time. An instructor may hear this call, which resonates with her/his conception that students need to "do" to learn, and then give group work a try. But the students may resist participating, they may even stop coming to class, start discussing their weekend plans, or protest to the department head. After some amount of effort the instructor is likely to abandon the practice concluding that, although it seems to work well at university *X*, it is not a suitable method for them or their situation. Thus, by the time an instructor has identified some of the situational barriers, the chance for reform has been lost.

It would be better if instructors were provided with the information and tools to anticipate possible implementation difficulties due to situational barriers (for example, the chairs being bolted down, the class size being large, pressure to move too fast due to content coverage, the many years students have spent learning that school is about passively collecting facts). If an instructor could see these issues as a source of trouble then s/he would be in a better position to make appropriate modifications to the instructional strategy while, at the same time, working toward change, for example petitioning the administration to unbolt the chairs or add an assistant to the classroom.

The question for the research community becomes; how can we help instructors to gain an awareness of the situational barriers they will face? And, once instructors identify these barriers how can they go about changing them. After all, getting the chairs unbolted is often a nontrivial task.

VI. CONCLUSION

We present evidence that major impediments to the spread of research-proven reforms are situational characteristics consistent with traditional instruction. We argue that dissemination efforts could be improved by accounting for this reality. Additionally, we encourage the research community to document these barriers and form theories to guide an understanding of the nature of the barriers. Of course, the findings of a small exploratory study such as this one are appropriately used primarily for the generation of new theoretical constructs that can be tested in larger, more focused studies. We intend to use the results in this manner and present the constructs here so that others who are interested can do the same.

ACKNOWLEDGMENTS

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