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The challenges of instructional change under the best of circumstances: A case study of one college physics instructor

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Physics education researchers have compiled substantial evidence that student course outcomes can be improved if physics instructors incorporate research-based instructional strategies into their teaching. Some instructors find this evidence convincing and attempt to change their instruction. Some of these instructors are successful and some are not. This paper presents the results of a case study of an experienced physics instructor as he attempted to change his instructional practices. Although the instructor appeared to have the prerequisites for successful change, he still encountered difficulties. Four factors were identified that limited his ability to change: an implicit instructional model, incomplete knowledge of instructional strategies, overly optimistic initial planning, and a desire to work within perceived external constraints. Contrary to common models of instructional change, the instructor did not attempt to learn many details about available techniques and engaged in a significant amount of invention of new techniques and reinvention of existing techniques.
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I. INTRODUCTION

During the last few decades there has been increasing awareness that traditional introductory college physics instruction is not producing the desired student outcomes. Students often leave traditional introductory physics courses with poor understanding of physics concepts,[1–4] poor problem-solving skills,[5–8] poor understanding of the processes of science,[9–12] as well as negative attitudes toward science.[13,14] The physics education research community has been using research on teaching and learning to develop innovative instructional strategies and materials that have been shown to improve student outcomes in all of these areas.[15–22] In spite of the availability of a wide variety of high-quality innovative instructional strategies, many physics instructors continue to use traditional instructional practices. This lack of use of "good ideas supported by convincing evidence of efficacy"[23] suggests that there are substantial barriers to change. To date, little research has been focused on identifying these barriers or uncovering the details of the change process.

One substantial barrier to change is that many physics instructors remain unconvinced by the evidence presented by the physics education research community. Other instructors, however, are convinced by the evidence and attempt to make changes in their instruction. Although the author was not able to find any studies of the rate of success of these instructors in changing their instructional practices, anecdotal evidence suggests that many have difficulties and a significant portion return to their traditional instructional practices. Finding a way to help more of these instructors become successful in changing their instruction could significantly increase the use of research-based instructional strategies. The goal of this study was to better understand the process of change and to identify impeding factors. Instructors can use this knowledge to anticipate and thus minimize or avoid the effects of these factors. Curriculum developers and professional development providers can use this knowledge to better support instructors who are attempting to change their instruction.

Rogers' model of the innovation-decision process[24] will be used as a starting point for organizing the change process of a particular physics instructor. First, it will be shown that Rogers' model offers a reasonable description of the change process. Then, four factors will be identified that impeded the change process.

II. BACKGROUND: INSTRUCTIONAL CHANGE

There is a body of literature that explores how individuals decide to adopt a new idea or practice.[24–27] Rogers' developed a widely accepted model of this process that is shown in Fig. 1 and is summarized in the following. This model is based on research on the adoption of innovations in a variety of fields including education, public health, communication, and marketing.[24]

Prerequisites. A prerequisite to an instructor learning about an instructional innovation is that the instructor must be dissatisfied with aspects of his/her current instruction. In addition, an instructor's beliefs and values about teaching and learning, previous instructional practices, and the norms of the school/department can all influence an instructor's decision to enter the change process as well as the types of changes considered.

Stage I: Knowledge. In this stage, the instructor gains knowledge about the innovation. There are three basic levels

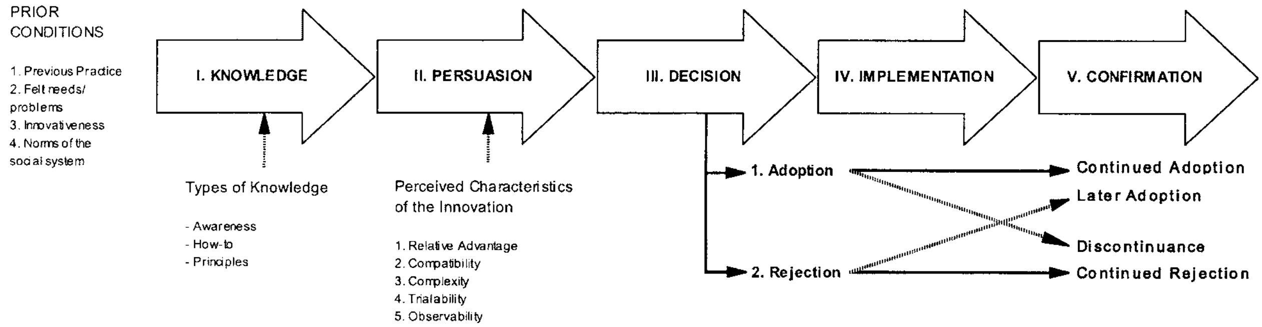

Fig. 1. Rogers' model of the innovation-decision process, Ref. 24, p. 163.

of knowledge: "awareness" knowledge (knowledge that the instructional strategy exists), "how-to" knowledge (knowledge about how to use the strategy properly), and "principles" knowledge (knowledge about why the strategy works—essential for solving problems that occur during use).

Stage II: Persuasion. Based on the knowledge gained, the instructor forms a favorable or unfavorable attitude toward the innovation. According to the model, there are five interrelated factors that influence the formation of this attitude, which have been shown to explain between 49% and 87% of the variance in the rate of adoption:[24,25]

(1) *Relative Advantage*. Is it better than what I do now?
(2) *Compatibility*. Does it conflict with my current beliefs about learning and teaching, or my current teaching practices?
(3) *Complexity*. Is it too difficult to understand or use in my teaching environment?
(4) *Trialability*. Can I try it out and return to what I was doing if I don't like it?
(5) *Observability*. Can I watch someone else using it before I decide whether to adopt?

Stage III: Decision. Based on the attitude formed, the instructor makes a decision about whether to adopt or reject the innovation. In some cases what appears to be a decision to reject is the result of an instructor never seriously considering its use.

Stage IV: Implementation. The instructor tries all or part of an innovation. The instructor does not necessarily implement the innovation as intended by the developer.

Stage V: Continuation. This decision is usually based on its perceivedsuccess in increasing the satisfaction with the previous instruction. One danger is the implementation dip,[26] the tendency for performance to become worse before it becomes better as the instructor grapples with the new skills and assumptions that change requires.[23,24,26,28] This dip may lead an instructor to decide to discontinue using the innovative instructional strategy.

III. DATA COLLECTION AND ANALYSIS

The goal of this study is to develop a detailed understanding of the educational change process of one physics instructor as he attempted to change his instructional practices during one academic semester (the case).[29] This understanding will be used to obtain insight into the difficulties of educational change in college level physics and, perhaps, educational change in general.

A. The case

Dr. Holt (a pseudonym) is a tenured faculty member who has taught physics at a research university in the upper Midwest for 20 years. He was selected because he was planning to change his instruction in the second semester introductory calculus-based physics (electricity and magnetism) class. The class consisted of about 70 students, mostly engineering majors, and met in a stadium-style lecture room for 50 min each weekday. In addition to the lecture, there was a weekly 2-h lab.

Dr. Holt appeared to have all of the prerequisites for successful change. He was dissatisfied with his previous experiences teaching this course and believed that changing his instructional practices could have a significant impact on student learning—in contrast to blaming students' poor preparation or lack of motivation for unsatisfying course outcomes.[30] He had taken the initiative to learn about instructional strategies and materials based on physics education research. He also was participating in a national program to improve introductory physics teaching. As part of this program he had the support of a teacher-in-residence—an experienced high-school teacher who frequently attended the class and discussed instructional strategies with him. In addition to the support afforded by the national program, there was also a degree of accountability because Dr. Holt knew that he would have to report on his experiences. A final level of support was provided by the weekly interviews that were part of this study. These interviews provided an opportunity for reflection on the past week and thinking about the coming week.

Dr. Holt had taught this course about 30 times and described developing his current instructional practices through these experiences. His goal for the course had always been to have students develop a real understanding of physics concepts that they could use to solve novel problems. Early in his teaching, he adjusted his expectations because this goal seemed out of reach: "They [the students] want to be given a formula they can plug things into, find an answer. And no matter how often I tell them that that's not what the course is about, it didn't get through that that wasn't what the course was about. Eventually, frankly, I had to make that what the course was about just in order to pass a reasonable number of students. So, I was fairly dissatisfied with the instruction." He described developing his instructional style and materials largely by trial and error: "I've tried to improve ever since [my first semester of teaching]. You just keep trying things and seeing if they work or not, you know, and what I've done

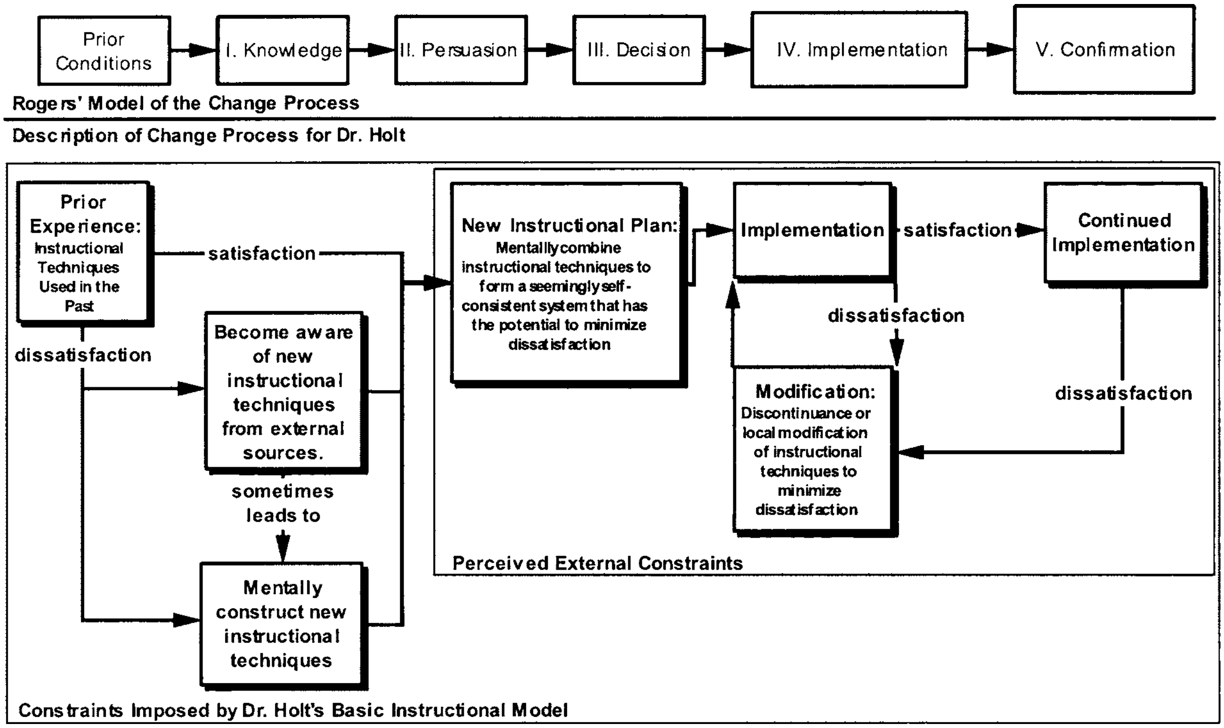

Fig. 2. A schematic of Dr. Holt's change process. The two large boxes enclosing parts of the change process represent constraints that limited these aspects of the change process. Rogers' model of the change process is shown for comparison.

is to hit on a set of lectures or presentations which take up the right amount of time and cover more or less the right amount of material."

B. Data sources

Case study research relies on multiple sources of evidence.[31] In this study, three principal sources of evidence were used: Weekly interviews with the course instructor (15 interviews ranging from 20 to 60 min each); Daily classroom observations (62 of the 67 class days were observed); and materials distributed to students (syllabus, exams, and homework). Because the goals of the study were to understand the process of instructional change, the focus of the data collection was on three dimensions of teaching practice:[26] instructional materials, instructional strategies, and beliefs about instruction. The daily classroom observations and student materials were used to document instructional materials and strategies. The reasons for the selection of the materials and strategies were discussed during the interviews along with other relevant beliefs.

The weekly interviews were conducted each Friday afternoon by the author and followed a standard format. The first part of the interview focused on Dr. Holt's reflections on the current week. The second focused on his plans for the following week. Each part of the interview started with open-ended questions, for example, "How do you think things went this week?," "What are your goals for next week?," and "How do you plan to accomplish these goals?" The answers were followed by more specific questions that often asked for more details, for example, "How do you decide when to [have the students] do something in groups versus when you lead a call-and-response kind of development?" Other questions asked Dr. Holt to restate or clarify his ideas, for example, "So, an important part of your strategy [for using white boards] is having some individual time with the groups?," or were challenging, for example, "It seems like you're doing very little problem solving in class."

C. Data analysis

The interviews were audio recorded and transcribed. A matrix display was used to organize the relevant information from the data sources by topic (rows) and by time (columns).[32] These topics included the various instructional strategies that were discussed, for example, the use of white board group work, assigning reading questions, and other topics that arose in the interviews, for example, the general level of instructor satisfaction with the course, estimation of level of student understanding, and instructor concerns. There were two columns for each week, one containing plans for the week and the other containing reflections on the week. The latter also contained information about actual practices from the class observations and student materials. This arrangement of data facilitated the identification of changes in ideas or practices in time as well as the identification of discrepancies between practices, goals, and reflections.

A model was developed to describe Dr. Holt's change process. Using Rogers' model of adoption of innovations as a starting point,[24] this model was developed iteratively by following Dr. Holt's statements about each of the instructional strategies and their use throughout the semester. The model development process was considered complete when the model accurately described the implementation of each of the instructional strategies.

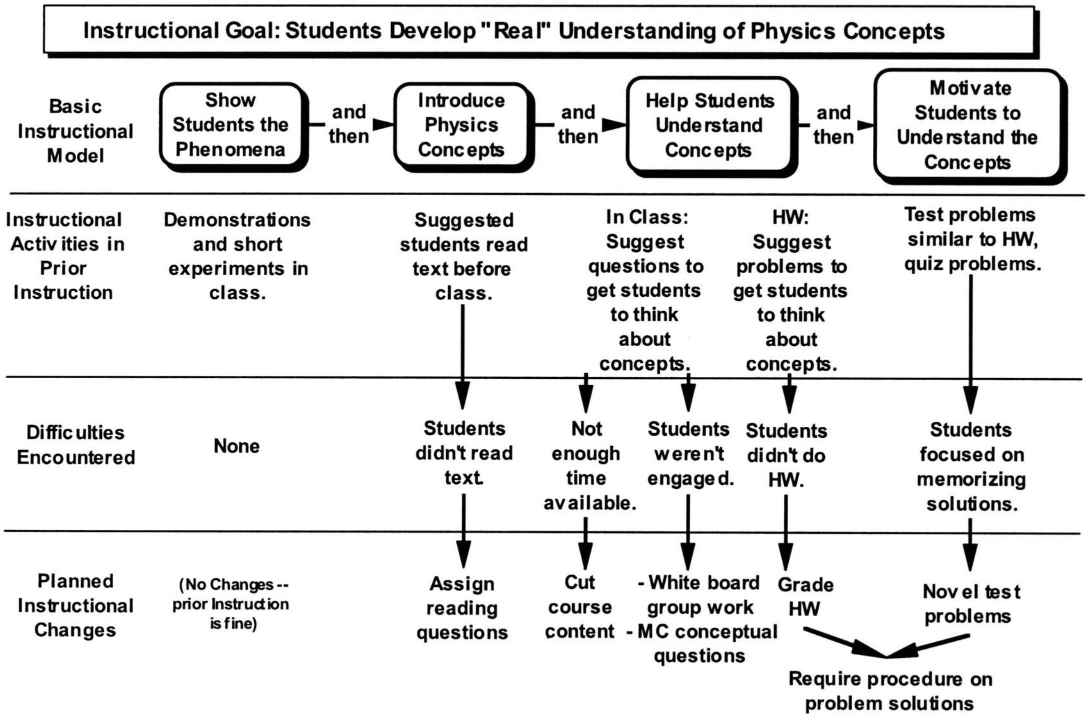

Fig. 3. A schematic showing the relation between Dr. Holt's basic instructional model, instructional activities used in the past, difficulties encountered, and new instructional activities. All planned instructional changes resulted directly from difficulties encountered in past instruction.

D. Credibility

Efforts were made to ensure that the study provided an authentic portrait of the change process as experienced by this physics instructor.[32] As Yin has suggested,[31] multiple sources of evidence were used, and all results were based on the complete set of evidence. In addition, Dr. Holt reviewed and commented on the results of this study. All of the results reported in this paper have been confirmed by him.

IV. RESULTS

A. Characteristics of Dr. Holt's change process

A schematic of Dr. Holt's change process is shown in Fig. 2 and the important characteristics are described in the following.

Dr. Holt had a coherent instructional model that constrained/guided the change process. The constraints imposed by this instructional model are represented by the box around the change process in Fig. 2. The instructional model was inferred from statements that Dr. Holt made during the interviews and is shown on the top row in Fig. 3. It was presented to him toward the end of the semester and immediately recognized as accurate. Although he was not explicitly aware of this instructional model (until it was presented to him), it nonetheless served to limit the options that he considered during the change process.

According to Dr. Holt's instructional model, there are four basic instructional activities that need to occur in a particular order. First, students are shown a new physical phenomenon. For example, the instructor shows two positively charged pith balls repel one another. Second, the physics concepts are introduced. For example, the instructor introduces Coulomb's law. Dr. Holt believes that this introduction can be done in class, but it also can be done by having students read the textbook, leaving more class time for other activities. Third, questions are asked or problems are assigned to help students develop an understanding of the concepts. For example, the instructor presents students with different situations and has them determine when the objects involved can be considered point charges so that Coulomb's law can be used. Fourth, students are motivated to understand the concepts by being required to solve novel problems on tests. Dr. Holt believes that if the test questions are not novel, then students will focus on memorizing problem solutions rather than understanding the concepts.

One aspect conspicuously absent from Dr. Holt's instructional model is any mechanism to help students use their knowledge of the physics concepts to solve problems. This absence reflects Dr. Holt's belief that all a student needs in order to solve problems is a good understanding of the physics concepts. Dr. Holt developed his instructional theory through a combination of his personal experience as a student and his prior teaching experiences. The influence of these factors on the development of Dr. Holt's instructional practices is consistent with the results of prior research.[33,34]

Dr. Holt sought or developed new instructional techniques to solve specific problems that had prevented full implementation of his instructional model in the past. He identified dissatisfaction with his past instructional techniques that he had used to address almost all of the basic instructional activities in his instructional model. The consideration of specific instructional techniques to solve specific problems was his main focus when planning for his course. The results of this planning are shown in Fig. 3 and are described in the following:

(1) *Introduce physics concepts*. Although Dr. Holt believed that physics concepts were most efficiently introduced in the reading, he believed that most students did not actu-

ally read the text. Thus, in his past instruction, he used class time to introduce the concepts instead of spending more time helping students understand the concepts. He was aware of several ways to enforce or encourage students to read the text, such as Mazur's suggestion of giving short reading quizzes.[19] Dr. Holt also developed the idea of asking students to submit a question that they had about the reading.

(2) *Help students understand the concepts in class*. One way that Dr. Holt believed he could help students understand the concepts was to suggest questions that encourage students to think about them. In the past he had not done this as much as he would have liked, because of the time constraints imposed by the need to cover much material and because he introduced the concepts in class rather than in the reading. In addition, when he did suggest questions in class, he believed that the students were not fully engaged in thinking about them. He was aware of several ways to make the students more engaged in thinking about the concepts during class. For example, he knew that small white boards could be used to facilitate group work,[35] concept-oriented tutorials[36] or multiple-choice tests[19] could be used to challenge student understanding, and students could be assigned to develop and do an experiment outside of class that related the physics concepts to their real-world experiences.

(3) *Help students understand the concepts by doing homework*. Another way that Dr. Holt believed he could help students understand the concepts was to suggest homework problems that encouraged students to think about the concepts. In the past he did not collect the homework and believed that many students did not attempt to do the problems. He realized that he could encourage students to do the homework by grading it. He was aware of various ways to grade homework assignments, including the use of online homework services.[37]

(4) *Motivate students to understand the concepts*. Dr. Holt believed that he needed to motivate students to understand the concepts by giving novel test questions. As mentioned, he had not been giving such questions in his instruction because he found that the students could not solve novel problems. One of his measures of success for the course was that students could solve novel problems on tests.

During planning for the course, Dr. Holt was aware of the aspects of his instruction that he wanted to change as well as a number of new instructional techniques. He was aware of some of these techniques through external sources, for example, by reading about instructional techniques used elsewhere and discussions with other instructors. Some of the techniques he developed himself. When learning about techniques from external sources, he tended to stop gathering information after developing an awareness that the technique existed (awareness knowledge), rather than developing knowledge about using the technique (how-to knowledge) or knowledge about why the technique works (principles knowledge).[24] He did not believe that talks, workshops, and written material could provide more than awareness knowledge. He believed that this additional knowledge was difficult or impossible to codify, and had to be developed by the personal experience of using a particular instructional technique and/or watching the instructional technique being used by another instructor for an extended period of time—at least a week.

Dr. Holt developed a new instructional plan before the start of the course. In constructing his plan, he mentally combined instructional techniques that he had used before with new instructional techniques to form a seemingly self-consistent system that was consistent with his basic instructional model and perceived external constraints. The most prominent constraint was the need to cover certain topics; however other constraints were mentioned from time to time, such as the layout of the lecture room or limited availability of a teaching assistant for grading. Table I shows specific instructional strategies that were part of this instructional plan, and Fig. 3 shows how these strategies related to his instructional model. The plan included an instructional cycle where one lecture would be used showing students the phenomena. That evening, students would be introduced to the basic physics concepts related to the phenomenon by reading the text. He planned to encourage students to read the text by requiring them to submit a question about the reading via email before the next lecture. During the next lecture, various activities would be used to get the students to think about the concepts. The most prominent of these activities was the use of small student groups working with white boards to think about a conceptually important question or problem. The additional class time required for these in-class activities would be available because there would be no need to introduce the physics concepts in class, and several topics previously covered in the course were omitted. In addition, students would be given regular homework assignments. After collecting student homework, one problem would be selected for thorough grading. Dr. Holt planned to give novel exam questions. To focus students on the physics concepts, he planned to require students to write a procedure for most of the problems that they solved for homework or on exams.

After initial implementation of his new instructional plan, Dr. Holt made local modifications. Once the course began, Dr. Holt began to modify his instructional plan. Aspects that dissatisfied him were either discontinued or modified. For example, he almost immediately revised his planned instructional cycle. Instead of separately showing the phenomena, introducing the concepts, and helping students understand the concepts, he found it was preferable to integrate these activities. Some aspects of his initial instructional plan were initially perceived to be satisfactory, but were later modified due to dissatisfaction. For example, the use of novel exam questions was slowly phased out during the second half of the semester in response to student performance. On the final exam, all of the questions were reasonably similar to questions given on previous quizzes. Some aspects of the initial instructional plan continued to be satisfactory for the entire semester and were retained. For example, Dr. Holt perceived the reading questions to be very successful in encouraging the students to read and think about the concepts before coming to class.

B. Differences between Dr. Holt's change process and Rogers' model

Rogers' model of the innovation-decision process appears to be consistent with most of the major aspects of Dr. Holt's change process. The stages in Rogers' model are more general than those in Dr. Holt's change process, but this generality would be expected because Rogers' model was devel-

Table I. New instructional strategies that were part of Dr. Holt's instructional plan.

New instructional technique	Plan	Implementation/results
Instructional sequence	(1) Show students the phenomena in one lecture. (2) Have students read the relevant concepts that evening. (3) Have them use the concepts in the subsequent lecture.	Basic activities were employed, but integrated much more than planned.
Multiple-choice conceptual questions	Students hold up a sheet of paper to identify their answer.	Used only during the first week of class.
Novel problems on tests	Tests to consist of problems that are sufficiently different from previously assigned problems to encourage "real understanding."	Initial tests contained novel problems, but later tests had problems that were more and more similar to the homework or in-class work. All of the final exam problems were similar to problems on prior quizzes. Dr. Holt believes that student understanding is similar to previous years.
Problem-solving procedure	Students are required to write a procedure for all homework and test problems.	Used throughout the course. No explicit description of the nature of an appropriate procedure and few examples presented to students. Dr. Holt believes that student solutions were easier to understand than in the past, but test performance was not noticeably improved.
Reading questions	Students submit a question about the assigned reading. Basic concepts from the reading are not presented in class.	Used throughout the course. Dr. Holt believes that the submissions were successful in encouraging students to read the text before class. Some basic concepts from the reading were presented in class.
White board group work	Students work together in assigned groups to develop a procedure for solving a complex problem.	Group work tended to focus on qualitative questions and was used about every other class period. Groups were initially assigned, but assignments were not enforced. Most groups were ad-hoc. Dr. Holt expressed concern that group work required much class time and that many students became progressively less engaged as the course progressed.

oped to represent the commonalities of the change process in many different situations. There are at least three important differences between Rogers' model and Dr. Holt's change process:

(1) *The innovations did not all come from external sources*. According to Rogers' and other models of the change process,[24–27] all of the innovations are developed externally to the person making the changes. In Dr. Holt's case, at least one of the important innovations, the use of reading questions, was developed entirely by him.

(2) *Implementation decisions were based on minimal knowledge about the innovations*. According to Rogers' model, a potential innovator bases an adoption decision on substantial knowledge about the innovation. Dr. Holt did not seek extensive information about innovations before making a decision (he mainly gained awareness knowledge). He believed that most articles or books were not detailed enough to provide information that would help him evaluate or use the innovations.

(3) *All innovations from external sources were changed significantly*. Because Dr. Holt did not seek to gain how-to or principles knowledge about these innovations, he developed his own procedures for their use. Although Rogers' model allows for modification of an innovation, it does not reflect the large differences between the intended and the implemented innovations that were ob-

served in this study. Some models of the educational change process allow for significant differences, but see them as refinements that are made only after the instructor has become proficient in using the innovation more or less as designed.[38] In contrast, the two major innovations from external sources, the use of white board group work in class and the use of a problem-solving procedure, were significantly modified by Dr. Holt for implementation in his class. In the modification, many features previously shown to be crucial to successful implementation of the original innovation were lost.

C. Impediments to change

The main goal of this study was to identify factors that prevent an instructor from reaching the desired improvement in student outcomes that initiated the change process. Table I shows the instructional strategies that were part of the initial plan, how these strategies were implemented, and how satisfied Dr. Holt was with their use. Throughout the study, the author developed hypotheses about factors that seemed to impede the change process. Once the study was completed, these factors were tested against the change process for each identifiable instructional technique used by Dr. Holt. Four factors were identified that were consistent with the change process for each instructional technique. They were modified slightly based on comments by Dr. Holt.

Factor 1: Dr. Holt's instructional model constrained his instructional choices. His instructional model was implicit, unquestioned, and did not appear to change throughout the semester. Dr. Holt did not consider instructional techniques or look for explanations that fell outside of his instructional model. Most of his model was compatible with the results of educational research and helped to effectively guide the change process. Other parts limited the change process. For example, as mentioned, Dr. Holt believed that if students really understood the physics concepts, they would be able to solve problems based on these concepts. Thus, he placed a lot of emphasis on conceptual understanding and relatively little on developing students' problem-solving skills. Educational researchers, however, believe that conceptual understanding is only one of the necessary components of an individual's ability to solve problems.[39] A lack of instructional emphasis on problem solving might have been one of the factors limiting students' abilities to solve novel problems at the end of the course. This factor is consistent with research that has shown that a teacher's beliefs about teaching and learning can constrain thinking.[40–42]

Factor 2: Dr. Holt did not seek to gain much knowledge about new instructional techniques. As discussed, Dr. Holt only obtained awareness knowledge about instructional strategies before attempting implementation. In some cases this lack of how-to or principles knowledge led to implementation difficulties. For example, when implementing white board group work, Dr. Holt did not take the time to have groups share their solutions with one another or with the class. He also decided not to assign a grade to group work. As the semester progressed, he found that less and less of the class took these assignments seriously. His implementation of white board group work did not reflect the five essential components of cooperative grouping,[43] of which Dr. Holt was unaware. Some of this knowledge about the successful management of groups was developed by Dr. Holt by reflecting on his dissatisfaction with student behavior toward group work. For example, he realized that he could probably encourage the students to work more seriously on group tasks by grading the results or the process. He did not attempt to look for information about how other instructors had handled this problem and decided not to try to implement any changes in his approach to group work.

It is not clear if it would have been possible for Dr. Holt to avert these difficulties by attempting to obtain principles knowledge before implementation. This knowledge might not have made sense without some relevant prior experience. It seems likely, however, that developing some how-to knowledge about possible ways to manage small group work in class could have averted some of the difficulties.

Factor 3: Planning was overly optimistic. Dr. Holt's initial plans for the course were very elaborate and did not anticipate possible problems such as the students not behaving as expected or the course elements not fitting together as hoped. For example, his planned instructional sequence (showing students the phenomena in one lecture, having them read about the relevant physics concepts that evening, and then having them use the concepts during the following lecture) was found to be constraining and very quickly discontinued. In addition, he did not anticipate the considerable time and energy that change requires. Developing new materials and reflecting on and refining instructional strategies took a significant amount of time and energy. When neither were available, Dr. Holt would revert to previous instructional practice of doing semi-interactive lectures where he would develop a topic by asking a series of questions of the class and having students call out answers.

Factor 4: The implementation of the new instructional plan was overridden by perceived external constraints. In addition to not anticipating how much of his personal time and energy the planned instructional strategies would require, he also did not anticipate how much instructional time some of these strategies would take. A common concern expressed during the interviews was the need to cover material. This concern led Dr. Holt to revert to his previous instructional practices. For example, he believed that well-designed white board group work was very effective in helping students understand the physics concepts. But because it took much time, semi-interactive lectures often were chosen instead in order to cover the necessary material.

V. DISCUSSION

This study is an example of the process of instructional change in higher education. It suggests that standard models of the educational change process can provide a useful structure for understanding instructor change. However, these models of the change process might not take into account the significant amount of invention of new instructional techniques and reinvention of existing techniques that takes place in instructor change. Existing models suggest that instructors learn about all of the options and then make a choice to use one or more of them with, at most, minor adaptations. That did not occur in this case. Of course, this study was limited to only a single instructor, so more work is needed to determine if this level of invention is special to this instructor, is a feature of only tertiary level instructional change, or is a general feature of instructional change.

In addition, this study confirms the findings of previous studies that a desire to change, although necessary, is not enough for change to be successful.[44] In this study, Dr. Holt's ability to change was limited by his beliefs about teaching, his lack of how-to and principles knowledge of instructional strategies, his overly optimistic initial planning, and his desire to work within perceived external constraints. Because other studies have suggested that it takes a teacher between 3 and 5 years to successfully change instructional practices,[26,45,46] this one-semester case study might represent only the initial phase of a successful long-term change process. Dr. Holt has indicated that he plans to use the results of this initial experience to continue working toward his goal of helping students develop a real understanding of physics concepts.

VI. IMPLICATIONS FOR INSTRUCTORS AND CURRICULUM DEVELOPERS

Change is intrinsically difficult because it requires the acquisition of new skills and beliefs.[26] The difficulties encountered by Dr. Holt suggest several pieces of advice for instructors who are interested in changing their instruction.

(1) Focus on a few changes, rather than trying several changes at once.
(2) Problems are a natural part of change—expect them.
(3) Change requires substantial mental energy and time—make sure that it is available.
(4) Learn as much as you can about previous innovations. Knowledge can avert some problems, but some aspects of a new instructional strategy probably cannot be fully understood without experience.

Curriculum developers and professional development designers hope to change instructors' teaching practices by helping them successfully use research-based instructional strategies. They often are frustrated that many instructors never attempt to use these new instructional strategies. An additional frustration is that many instructors who do attempt to use a new instructional strategy do not use it as designed and/or quickly discontinue its use. The results of this study suggest several ways that curriculum developers and professional development providers might help to improve this situation.

As was the case in this study, innovative instructional strategies and materials might be reinvented by each user. A change process based on invention and reinvention has several implications for curriculum developers. The first is that innovations must be robust. They should degrade gracefully under modification and/or partial use. Another is that innovations are more likely to be used if it is easy for an instructor to pick and choose parts of the innovation.[24] It would be helpful if curriculum developers designed modular materials that can be modified easily. Curriculum developers also should clearly identify the essential elements of the innovation. There often are multiple ways to accomplish an essential element; however, without consideration of this element, the innovation may fail. Many innovations do not have clearly identified essential elements. For example, in this study an awareness of the five essential elements of cooperative grouping[43] might have allowed Dr. Holt to consider modifications to his new instructional plan, or given him some ways to deal with the initial implementation difficulties of white board group work.

One of the results of this study is that Dr. Holt's instructional model was very important in determining what changes he considered and how he implemented these changes. This filtering effect of Dr. Holt's instructional model is consistent with research on teachers' conceptions[41,47,48] and suggests that it is important for curriculum developers and professional development providers to understand instructors' instructional models. Dr. Holt's instructional model was largely consistent with the results of educational research and helped to facilitate the change process in many areas, but other instructors might not have such a model.

Instructional change is a long-term evolutionary process. New practices and beliefs are built on previous practices and beliefs.[49] Although Dr. Holt's instructional model did not change during the semester, he indicated dissatisfaction with aspects of his instruction that he wanted to investigate more before teaching the course again (for example, managing student groups and ways to teach problem-solving skills). After being shown the author's representation of his instructional model, Dr. Holt indicated that his instructional model may need to be modified to help students develop problem-solving skills that they do not develop under his current model. It is unclear, however, if he would come to this realization without the intervention of this study or if this realization will actually lead to a change in his model. Thus, it is important for curriculum developers to be willing and able to work with instructors for an extended time as the instructors develop increasingly sophisticated levels of knowledge and skill.

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[1]I. A. Halloun and D. Hestenes, "The initial knowledge state of college physics students," Am. J. Phys. **53**, 1043–1055 (1985).
[2]R. R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," Am. J. Phys. **66**, 64–74 (1998).
[3]J. H. Wandersee, J. J. Mintzes, and J. D. Novak, "Research on alternative conceptions in science," in *Handbook of Research on Science Teaching and Learning*, edited by Dorothy Gabel (MacMillan, New York, 1994).
[4]L. McDermott, "Research on conceptual understanding in mechanics," Phys. Today **37**, 24–32 (1987).
[5]D. Maloney, "Rule-governed approaches to physics: Newton's third law," Phys. Educ. **19**, 37–42 (1984).
[6]A. Van Heuvelen, "Learning to think like a physicist: A review of research-based instructional strategies," Am. J. Phys. **59**, 891–897 (1991).
[7]F. Reif, "Millikan Lecture 1994: Understanding and teaching important scientific thought processes," Am. J. Phys. **63**, 17–32 (1995).
[8]J. H. Larkin, J. McDermott, D. P. Simon, and H. A. Simon, "Expert and novice performance in solving physics problems," Science **208**, 1335–1342 (1980).
[9]A. E. Lawson, "A review of research on formal reasoning and science teaching," J. Res. Sci. Teach. **22**, 569–617 (1985).
[10]R. Millar, "Students' understanding of the procedures of scientific inquiry," in *Connecting Research in Physics Education with Teacher Education*, edited by A. Tiberghien, E. L. Jossem, and J. Barojas (International Commission on Physics Education, 1998).
[11]I. Halloun and D. Hestenes, "Interpreting VASS dimensions and profiles," Sci. Educ. **7**, 553–577 (1998).
[12]E. F. Redish, J. M. Saul, and R. N. Steinberg, "Student expectations in introductory physics," Am. J. Phys. **66**, 212–224 (1998).
[13]National Science Foundation, "Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology. A report on its review of undergraduate education by the advisory committee to the National Science Foundation Directorate for Education

and Human Resources'' (National Science Foundation, Arlington, VA, 1996).
[14]S. Tobias, *They're not Dumb, They're Different: Stalking the Second Tier* (Research Corporation, Tucson, AZ, 1990).
[15]A. Van Heuvelen, ''Overview, case study physics,'' Am. J. Phys. **59**, 898–907 (1991).
[16]P. Heller and M. Hollabaugh, ''Teaching problem solving through cooperative grouping. 2. Designing problems and structuring groups,'' Am. J. Phys. **60**, 637–645 (1992).
[17]P. Heller, R. Keith, and S. Anderson, ''Teaching problem solving through cooperative grouping. 1. Groups versus individual problem solving,'' Am. J. Phys. **60**, 627–636 (1992).
[18]L. McDermott and P. S. Shaffer, *Tutorials in Introductory Physics* (Prentice–Hall, Upper Saddle River, NJ, 1998).
[19]E. Mazur, *Peer Instruction: A User's Manual* (Prentice-Hall, Upper Saddle River, NJ, 1997).
[20]P. W. Laws, ''Calculus-based physics without lectures,'' Phys. Today **44**, 24–31 (1991).
[21]D. R. Sokoloff and R. K. Thornton, ''Using interactive lecture demonstrations to create an active learning environment,'' Phys. Teach. **35**, 340–342 (1997).
[22]E. F. Redish, *Teaching Physics with the Physics Suite* (Wiley, Hoboken, NJ, 2003).
[23]E. Seymour, ''Tracking the process of change in US undergraduate education in science, mathematics, engineering, and technology,'' Sci. Educ. **86**, 79–105 (2001).
[24]E. M. Rogers, *Diffusion of Innovations* (Simon & Schuster, New York, 1995).
[25]J. B. Ellsworth, *Surviving Change: A Survey of Educational Change Models* (Office of Educational Research and Improvement, Washington, DC, 2000).
[26]M. Fullan, *The New Meaning of Educational Change* (Teachers College Press, New York, 2001).
[27]J. Foertsch, S. B. Millar, L. Squire and R. Gunter, ''Persuading professors: A study of the dissemination of educational reform in research institutions,'' University of Wisconsin–Madison, LEAD Center, Madison, 1997.
[28]I. Mitchell, ''School-tertiary collaboration: A long-term view,'' Int. J. Sci. Educ. **16**, 599–612 (1994).
[29]R. E. Stake, ''Case studies,'' in *Strategies of Qualitative Inquiry*, edited by Norman K. Denzin and Yvonna S. Lincoln (Sage, Thousand Oaks, CA, 1998). See p. 88.
[30]C. Henderson, ''Faculty conceptions about the teaching and learning of problem solving in introductory calculus-based physics,'' Ph.D. dissertation, University of Minnesota, 2002.
[31]R. K. Yin, *Case Study Research: Design and Methods* (Sage, Thousand Oaks, CA, 2003).
[32]M. B. Miles and A. M. Huberman, *Qualitative Data Analysis: An Expanded Sourcebook* (Sage, Thousand Oaks, CA, 1994).
[33]J. H. v. Driel, D. Beijaard, and N. Verloop, ''Professional development and reform in science education: The role of teachers' practical knowledge,'' J. Res. Sci. Teach. **38**, 137–158 (2001).
[34]K. Carter and W. Doyle, ''Preconceptions in learning to teach,'' Educ. Forum **59**, 186–195 (1987).
[35]D. MacIsaac, ''Whiteboarding In The Classroom,'' The Arizona K-12 Center and the Arizona Teacher Excellence Coalition (AzTEC) Project, ⟨http://physicsed.buffalostate.edu/AZTEC/BP_WB/⟩.
[36]L. McDermott and P. S. Shaffer, *Tutorials in Introductory Physics* (Prentice–Hall, Upper Saddle River, NJ, 2002).
[37]S. Bonham, R. Beichner, and D. Deardorff, ''Online homework: Does it make a difference?,'' Phys. Teach. **39**, 293–296 (2001).
[38]G. E. Hall and S. M. Hord, *Change in Schools: Facilitating the Process* (State University of New York Press, Albany, 1987).
[39]D. Maloney, ''Research on problem solving: Physics,'' in *Handbook of Research on Science Teaching and Learning*, edited by Dorothy Gabel (MacMillan, New York, 1994).
[40]J. Calderhead, ''Teachers: Beliefs and knowledge,'' in *Handbook of Educational Psychology*, edited by D. C. Berliner and R. C. Calfee (Prentice–Hall, New York, 1987).
[41]M. F. Pajares, ''Teachers' beliefs and educational research: Cleaning up a messy construct,'' Rev. Educ. Res. **63**, 307–332 (1992).
[42]J. Nespor, ''The role of beliefs in the practice of teaching,'' J. Curriculum Studies **19**, 317–328 (1987).
[43]D. W. Johnson, R. T. Johnson, and E. J. Holubec, *Cooperation in the Classroom* (Interaction Book Company, Edina, MN, 1993).
[44]C. Briscoe, ''The dynamic interactions among beliefs, role metaphors, and teaching practices: A case study of teacher change,'' Sci. Educ. **75**, 185–199 (1991).
[45]F. Lawrenz and D. Huffman, ''Science education reform: The impact of teacher enhancement and curriculum implementation on student performance 1995–2001,'' University of Minnesota, Center for Applied Research & Educational Improvement, Minneapolis, MN, 2002.
[46]S. Loucks-Horsley, P. Hewson, N. Love, and K. Stiles, *Designing Professional Development for Teachers of Science and Mathematics* (Corwin, Thousand Oaks, CA, 1998).
[47]R. Boice, ''New faculty as teachers,'' in *Teaching and Learning in the College Classroom*, edited by K. A. Feldman and M. B. Paulsen (Simon & Schuster, Needham Heights, MA, 1995).
[48]A. G. Thompson, ''Teachers' beliefs and conceptions: A synthesis of the research,'' in *Handbook of Research on Mathematics Teaching and Learning*, edited by D. A. Grouws (MacMillan, New York, 1992).
[49]R. B. Kozma, ''A grounded theory of instructional innovation in higher education,'' J. Higher Educ. **56**, 300–319 (1985).