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Promoting instructional change via co-teaching

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Physics Education Research (PER) has made significant progress in developing effective instructional strategies, but disseminating the background knowledge and strategies to other faculty has proven difficult. Co-teaching is a promising and cost-effective alternative to traditional professional development which may be applicable in particular situations. We discuss the theoretical background of co-teaching and describe our initial experience with it. A new instructor (Famiano) co-taught an introductory calculus-based physics course with an instructor experienced in PER-based reforms (Henderson). The pair taught within the course structure typically used by Henderson and met regularly to discuss instructional decisions. An outsider (Beach) conducted separate interviews with each instructor and observed several class sessions. Classroom observations show an immediate use of PER-based instructional practices by the new instructor. Interviews show a significant shift in the new instructor's beliefs about teaching and intentions of future use of PER-based instructional approaches.
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I. INTRODUCTION

Many funding models for promoting educational reform in the teaching of college science courses are based on the assumption that an individual or group of faculty develops and tests a research-based instructional strategy and then disseminates this strategy to colleagues at their home institution and at other institutions. Dissemination typically takes the form of large-scale transmission-oriented activities such as talks, workshops, and publications. Although such transmission-based dissemination can lead to successful instructional change, it is typically only the first step in the change process for an individual instructor. Support for subsequent steps of the change process is not a feature of most dissemination programs. This lack of subsequent support is likely one reason for the relatively low success rates of such programs.[1]

In this paper we identify some of the difficulties with common transmission-based dissemination models and describe an alternative apprenticeship model that is helpful in overcoming some of these difficulties in particular situations.

II. THEORETICAL BACKGROUND

In this section we briefly describe several assumptions that have shaped our thinking about educational reform: fundamental instructional changes are rare; instructional innovations require local customization; standard dissemination methods are not well suited for promoting fundamental change; new faculty typically struggle with their teaching responsibilities; and professional development can be thought of in terms of instructional paradigms. This description is not intended to be a comprehensive review of the literature on instructional change. Rather we seek to give the reader an understanding of our perspectives on some important themes that form the theoretical basis for this work.

A. Fundamental instructional changes are rare

Most reforms in science teaching call for a significant shift in the role of teachers.[1,2] In traditional educational systems the role of teachers is to be a content expert who can impart their knowledge to students.[3] Most reforms call for teachers to become a facilitator of the learning process. This call for a change in the role of the teacher occurs both at the K–12 level, where the National Science Education Standards call for instructional environments where "students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills,"[4] and at the college level, where the National Research Council's Committee on Undergraduate Science Education calls for undergraduate teaching faculty to "be prepared to use combinations of inquiry-based, problem-solving, information-gathering, and didactic forms of instruction under appropriate classroom circumstances that promote conceptual understanding and students' ability to apply knowledge in new situations."[5]

Cuban refers to such a shift as fundamental and distinguishes between fundamental and incremental changes.[6] According to Cuban, incremental changes seek to improve the efficiency and effectiveness of the system. The basic assumption behind an incremental change is that the basic system and structures are appropriate, but need minor adjustments to improve efficiency. Fundamental changes seek to change aspects of the basic system and/or structures. The basic assumption behind a fundamental change is that important aspects of the system are broken and that new systems or structures are needed. The distinction between incremental and fundamental change is important because fundamental changes usually face significant resistance while incremental changes often do not.[7] Thus, it is likely that different techniques are needed to bring about each type of change.

A major obstacle to the implementation of fundamental instructional change is that instructors who attempt to change their traditional practices are already acculturated into and surrounded by a culture that reflects their current practices.[8–10] Thus, they must undergo a difficult process of learning and cultural change. Even when instructors are able to successfully make internal changes, they are typically still immersed in their current situation, which is likely to conflict with their new teaching culture.[10] For example, in an interview study, physics faculty cited strong situational constraints that made it difficult to teach in a nontraditional manner.[11] Commonalities such as large class sizes, broad content coverage expectations, classroom infrastructure, scheduling constraints, and poor student preparation/motivation all appear to favor traditional instruction. Another significant barrier to instructional change is that the current incentive structures at most universities place significant emphasis on excellence in disciplinary research, but little emphasis on excellence in teaching.[1,6,12] In addition, students often resist new instructional strategies.[13,14]

B. Instructional innovations require local customization

It is unlikely that any set of instructional materials, no matter how carefully developed, will match the constraints of a particular instructor's situation. Even when instructors are convinced that their existing practice does not achieve an instructional goal that they value and are convinced that a new practice is appropriate, they still must have the knowledge, skill, and confidence to customize the new practice. Although the developers of instructional strategies may seek to improve the fidelity of implementation through their dissemination strategies (for example, by publishing materials that are difficult for instructors to modify) "there is no way to avoid the local reconstruction of the practice [instructional strategy], as local staff make sense of it in their own context."[15]

Because of the conflicts with existing cultures (both personal and institutional), instructional styles that call for fundamental changes (for example, transforming classrooms from passive to active learning) are often changed by instructors and implemented as incremental changes.[16] Although such an implementation may keep some of the superficial features of the innovation, it is still traditional instruction. For example, some instructors attempt to implement Peer Instruction[14] without the peer interaction component.[17,18] This implementation of a modified version of Peer Instruction allows these instructors to streamline their lectures and maintain a passive classroom, while appearing on the surface to have implemented a research-based innovation. Boice has reported that new college faculty self-described student-centered instruction was confirmed by observations in only about half of the cases, indicating that these faculty may have assimilated the ideas of student-centered instruction into their mental models of instruction so that some aspects that conflict with the existing cultures are modified to align with these cultures. Henderson and Dancy use the term *inappropriate assimilation* to describe this type of "adoption."[18] Innovations requiring fundamental changes appear to be susceptible to inappropriate assimilation.[19] One unfortunate result is that instructors who think that they have adopted an instructional strategy, but have inappropriately assimilated it into their prior instructional practices, may conclude that the strategy is ineffective.

C. Standard dissemination methods are not well suited for promoting fundamental changes

Although standard dissemination strategies such as talks, papers, and workshops may be suitable for the promotion of incremental changes, it is unlikely that such an approach to professional development can promote fundamental changes. The best outcome of such an approach is to motivate participants to begin to change their instruction and provide them with a starting point. Rarely is support provided for the next steps that these participants must take to change their beliefs and to learn enough about the new instructional strategy to modify it to suit their situational and personal characteristics.

An additional barrier to standard dissemination strategies is the complex nature of teaching itself. Similar to any complex task, much of a teacher's decision-making is implicit.[20,21] It would be an overwhelming task for a curriculum developer to make all of the necessary implicit decisions explicit and equally overwhelming for an instructor to attempt to internalize these decisions. The ability to make correct decisions implicitly is learned through experience and reflection.[21,22] What is correct may be different in different instructional cultures. For example, from the perspective of traditional instruction, it might be very important to learn how to respond to student questions with clear and thorough explanations. From the perspective of many research-based instructional strategies it might be more important to learn how to respond to student questions with appropriate questions for the student. The development of this implicit knowledge is shaped by a larger organizing perspective.[23] An instructor who is in an instructional environment that supports traditional instruction and has personal beliefs consistent with traditional instruction will need substantial support to develop the implicit knowledge necessary to implement research-based instruction. It is likely that changes in beliefs, changes in implicit instructional knowledge, and changes in teaching practice will occur simultaneously.

D. New faculty typically struggle with their teaching responsibilities

Many new science faculty have had teaching assistant appointments in graduate school. Few have taught a course of their own before their first faculty position. Thus, the first few years of a faculty member's first appointment are a formative time in the development of their teaching style and an ideal time for interventions aimed at promoting nontraditional instructional practices.[24] A desire to impact faculty during this formative period is the philosophy behind the Workshop for New Physics and Astronomy Faculty.[25]

An alternative view is that any departure from traditional instruction for new tenure-track faculty is dangerous because such changes might require more time than traditional instruction and result in lower student ratings—especially at first.[1] However, it is common for new faculty to spend a majority of their time on instructional activities and receive poor student ratings under normal conditions. Boice studied 77 new tenure-track faculty at two universities (one with a research emphasis and one with a teaching emphasis) during their first year.[26] By the middle of their first semester, most of the new faculty complained about the lack of collegial support and reported that lecture preparation dominated their time. Few of the faculty reported teaching skill as depending on anything other than their knowledge of content, and clear, enthusiastic presentation. Most described their classes as standard facts-and-principles lecturing and many had no plans for improving their teaching. Boice concluded that new faculty typically teach cautiously, defensively, and tend to blame low student ratings on external factors such as poor students, heavy teaching loads, and invalid rating systems. He suggested that new faculty would benefit from programs that helped them find ways to increase student participation while at the same time avoid overpreparing fact-based lectures.

We argue that because new faculty already struggle with learning how to teach, this is the time to assist them in developing an instructional style based on educational research. Providing this assistance initially is much more effective than allowing new faculty to struggle on their own to develop a traditional instructional style and then provide support to try and change that style after the instructor obtains tenure.

E. Professional development can be thought of in terms of instructional paradigms

The successful dissemination of an instructional strategy requires that an instructor learn how to act and/or think in new ways. Thus, it is fruitful to think about dissemination through the lens of teaching and learning theories. Farnham-Diggory proposes three instructional paradigms: behavior, development, and apprenticeship.[27] Each paradigm is characterized by its view about how experts and novices differ and the mechanism by which novices become experts.

In the *behavior paradigm* "novices and experts are on the same scale(s)"[28] and a novice becomes an expert through the process of accumulation. This paradigm is evident in some professional development programs that seek to expand the options available to faculty in their instructional "tool kit." The assumption is that experts and novices use the same criteria for determining whether a particular tool is appropriate or not. The difference is that the experts have more tools and so are more likely to have an appropriate tool available for a given instructional situation. This paradigm is likely to be appropriate for disseminating incremental changes.

In the *development paradigm* novices and experts have different personal theories or qualitative models. Novices become experts through the process of perturbation. This paradigm is evident in many professional development programs that seek to help faculty develop a new way of thinking about teaching and learning by contradicting their assumed transmissionist theories and helping them develop a particular set of personal theories compatible with constructivism. In contrast to development-based instructional activities (for example, the University of Washington tutorials[29]) that provide substantial support over an extended period of time to help students in this process, development-based professional development typically does not provide much, if any, extended support to help faculty develop their personal theories along with compatible instructional practices.[30]

In the *apprenticeship paradigm* "novices and experts are from different worlds and a novice gets to be an expert through the mechanism of acculturation into the world of the expert. Actual participation in this world is critical for two reasons: (a) much of the knowledge that the expert transmits to the novice is tacit, and (b) the knowledge often varies with context."[31] Dissemination activities in the apprenticeship paradigm are not commonly found in the research literature. They likely occur when an instructor is on sabbatical or accepts a post-doctoral position at an institution with a well-developed instructional strategy. The instructor learns how to implement this strategy by working with the developer and assisting with the actual delivery of instruction.

Typical dissemination strategies are based on teaching and learning theories rooted in the behavior or development paradigms. Co-teaching is based on a different set of teaching and learning theories rooted in the apprenticeship paradigm.

III. WHAT IS CO-TEACHING?

The practice of co-teaching was developed by Roth and Tobin to help preservice K–12 teachers develop the tacit knowledge necessary to be successful teachers.[32,33] Co-teaching is similar to the more traditional student teaching experiences common in most teacher preparation programs in that a preservice teacher is placed in the classroom of a master teacher. In standard student teaching the preservice teacher often plays the role of a passive observer who is eventually entrusted to take over the class for specific times. A feature of this arrangement is that the teachers divide responsibility for the work that needs to be done. Roth argues that preservice teachers do not often develop the tacit knowledge necessary to be good teachers under this arrangement.[32] The defining feature of co-teaching is that participants share responsibility for all aspects of a class.[34] Through this arrangement preservice teachers "begin to develop a feel for what is right and what causes us to do what we do at the right moment,"[35] which they would not develop through observation, taking classes, or teaching on their own. Although co-teaching activities have occurred at the college level at other institutions, we are not aware of other studies that have sought to document the results of such an arrangement.

As described earlier, new instructors are typically averse to risk and are afraid of making mistakes that may hurt their chances of getting tenure. Any teaching innovation has the potential for increasing student complaints as well as giving other faculty the impression that the new faculty member is placing an inappropriate priority on teaching over research. Thus, any departure from traditional instruction must be made as risk-free as possible in terms of both student satisfaction and time demands. Co-teaching, as done in this project, meets these requirements. It allows an experienced instructor to set up a course structure that is known to work in the particular context. This structure gives the new instructor a safe place to practice new ways of interacting in the classroom and minimizes the risks of problems arising while

Table I. Design principles of Western Michigan University PhysTEC courses.

(1)	Students should be actively engaged with the material during class time. This engagement is best accomplished via student-student interaction.
(2)	Students should read the text before coming to class and most will not do so unless there is some sort of enforcement.
(3)	Class discussions and tests should place significant emphasis on conceptual issues and qualitative questions.
(4)	Class discussions and tests should place significant emphasis on the solving of multi-step problems (that is, ones that cannot be solved by substituting numbers into a single equation).
(5)	Student problem solutions should start from basic principles and contain written explanation of their reasoning.
(6)	Test questions should require students to engage in the desired thinking processes. This requirement means that test questions should not be similar enough to questions students have previously seen that a rote strategy is fruitful.
(7)	Formative assessment, both informal and formal, should be used to determine students' current understanding for the purpose of designing appropriate subsequent instruction.
(8)	Depth of student understanding should be valued more than breadth of content covered during the course.

switching cultures. Both instructors are listed as the instructors of record so neither can be held fully responsible for any negative student evaluations.[36] During the co-teaching semester the new instructor has the benefit of using previously used materials and only has to prepare for being in charge of the class about half the time, leaving additional time and energy available for the more reflective aspects of co-teaching.

IV. THE CO-TEACHING PROJECT AT WESTERN MICHIGAN UNIVERSITY

The goal of co-teaching in the current study is to acculturate Michael Famiano, a new instructor and co-author of the study, into research-based physics instruction as embodied in the Western Michigan University Physics Teachers Education Coalition (PhysTEC) design principles—see Table I. The largely tacit and context-dependent nature of teacher decision-making means that learning to teach in a PhysTEC-compatible manner requires more than just talking about teaching—it requires direct experience in the practice of teaching. The assumptions and norms of PhysTEC are very different from that of traditional teaching.

A. Co-teaching activities and context

The co-teaching took place in Fall 2005 semester in the lecture portion of an introductory calculus-based physics course, Phys 2050: Mechanics and Heat, at Western Michigan University. The four credit course met each weekday for 50 min with about 70 students, mostly engineering majors, in a stadium-style lecture hall with fixed seating. Henderson and Famiano were both listed as instructors of record. Students were not told about the co-teaching project, and because it was their first physics course at Western Michigan, had no reason to think it was unusual to have two instructors. In addition to the lecture, each student participated in a weekly 2-h laboratory session taught by TAs under the supervision of other department staff. The lab activities had been redesigned under the PhysTEC project to focus on developing and extending student understanding of the relevant physics topics.

The class structure had been developed by Henderson as part of the Western Michigan University PhysTEC project through consultation with his colleagues. Ten important course components are described in Table II. These components are based on best-practices as identified in the educational research literature. Henderson was familiar with the research base behind these course components and had used these course components in previous semesters for both Phys 2050 and the next course in the introductory sequence on electricity and light.

There were five co-teaching activities which will be described briefly in the following and considered from the perspective of an apprentice instructional framework.[37,38]

(1) Henderson and Famiano alternated being in charge of the class each week, although both instructors were present during each class session. The instructor in charge typically presided over whole-class discussions or presentations. Much of the class time was spent by students working in assigned small groups. During this time both instructors circulated around the lecture hall and interacted with groups. The first draft of the weekly quizzes or exams was developed by the instructor in charge and shared with the other instructor for comments.

(2) Each Friday an hour meeting between Henderson and Famiano reflected on the previous week and initial plans for the coming week were discussed. During this time they talked about how things went during the past week and any difficulties that arose. The instructor in charge of the following week would then present his initial plans. In addition to this scheduled meeting, the instructors frequently had shorter discussions about the course at other times.

(3) The course structure was designed by Henderson so that much of the class time would have students working together in small groups while discussing important physics ideas. The course structure is summarized in Table II.

(4) Famiano had access to the materials used by Henderson in previous course offerings. At the beginning of the semester Henderson gave Famiano electronic copies of all the course activities and assignments used in the previous semester. Famiano used, with minor modifications, about half of these and developed the other half of the course activities himself.

(5) Famiano taught the same class on his own during the following semester, Spring 2006.

B. Co-teaching and apprenticeship

Co-teaching is based on an apprenticeship instructional paradigm. There are six basic aspects of a cognitive apprenticeship instructional model:[39] (1) Modeling: expert performs a task so novice can observe. (2) Coaching: expert observes and facilitates while novice performs task. (3) Scaffolding: expert provides support to help the novice perform the task. (4) Articulation: expert encourages novice to verbalize their

Table II. Significant course elements of Physics 2050 during Fall 2005 (co-teaching) and Spring 2006 (Famiano teaching alone).

Course component	Course component, Henderson and Famiano (Fall 2005)	Course component, Famiano (Spring 2006)
Encourage students to read the text before class	Reading assignment—students asked to submit a question about the assigned reading (Ref. 37) as well as to discuss an example problem from the reading assignment (Ref. 47). Typically due Monday evening—submitted via WebCT.	Reading quiz—WebCT quiz covering important aspects of the reading. Typically due Monday evening. (Approximately nine questions/week. Similar to Henderson/Famiano online exercises—highest of four chances)
Use of class time	During class time there may be short lectures (5–10 min) when new topics are introduced. But, most of the class time is spent with students working in assigned groups (and, usually, white boards) on instructor-assigned activities. Activities varied from conceptual questions to quantitative problems—all were designed or chosen to encourage discussion and thought about the physics topics and discourage rote learning. The instructor(s) moved around and interacted with groups. When the instructor noted that many of the groups were finished or stuck, he would hold a whole-class discussion. This would start by calling on a group (typically at random, but sometimes chosen based on observations).	
Assignment of groups	At the beginning of the semester, students are assigned to groups of 3–4 based on where they live (as homogeneous as possible) and their performance in the prerequisite math course and conceptual pretest (as heterogeneous as possible). Gender was also considered, but given less weight than the first two factors. Students remained in these groups throughout the semester.	
Online exercises	Each week 6–12 exercises were assigned. These consisted of conceptually oriented questions (often multiple-choice) or relatively simple calculations and were typically due on Wednesdays at class time. Grade recorded is average of up to four chances.	Used for reading quizzes
Online homework	Students were each responsible for completing their individual assignments on WebCT (although they were explicitly encouraged to work together). Each week four problems were assigned. These were similar to mid-level problems found in standard textbooks (they involved multiple steps and were specifically chosen to not be easily solvable by rote) and were typically due on Thursdays at class time. Grade recorded is average of up to four chances.	Online HW was optional
Written homework	Each group of students was responsible for turning in a written solution (using the problem solving format) to each of the four WebCT problems.	Each student was responsible for turning in a written solution for six to ten HW problems. Problems were similar (or identical) to the Henderson/ Famiano WebCT problems.
Problem solving framework	Students required to include the following aspects of a problem solution in their written work: General Approach (big picture description of how to solve the problem, including relevant physics principles), Procedure (details about how to solve the problem, including specific steps), and Implementation (working out the details and evaluating the result). The use of these three aspects was modeled by instructor during class.	The three aspects of a problem solution were emphasized in class but not required in student solutions. Student solutions were expected to start from basic principles and show reasoning.
Use of main ideas	The important physics concepts covered during the course were broken into 21 main ideas that were explicitly categorized, frequently referred to in class and provided to students on exams. All problem solutions were expected to be based on one or more main idea.	
Testing	Each week a quiz or exam was given. The weekly quizzes focused on the material covered during the week. Every third week, there was an exam that focused on the material covered during the previous three weeks. Each quiz and exam had a similar format. There were two to four conceptually-oriented short answer questions and one multi-step quantitative problem that required a solution using the problem solving format. There was also a final exam with three multi-part conceptual questions and three problems. Complete written solutions were available on WebCT shortly after each examination.	

Table II. (*Continued.*)

Course component	Course component, Henderson and Famiano (Fall 2005)	Course component, Famiano (Spring 2006)
Quiz corrections	After graded quizzes were returned, students had the option to complete a quiz correction assignment. The purpose of the assignment was to have students reflect on their quiz mistakes in light of the instructor solution and construct generalized physics knowledge. Quiz correction attempts resulted in an increased quiz grade of 50% of the lost points if done well and no change in the quiz grade if done poorly.	Not used

knowledge and thinking. (5) Reflection: expert enables novice to compare their performance with others. (6) Exploration: expert asks novice to perform additional tasks with decreasing support. Table III shows how each of the co-teaching activities matches with the cognitive apprenticeship instructional model.

C. Cost of co-teaching

In the co-teaching model described in this paper the only cost incurred was funding for a replacement instructor who was supported by an external grant to teach one class. The ability to hire a replacement instructor to teach a class that would otherwise have been assigned to either Henderson or Famiano allowed Henderson and Famiano to co-teach a single class and have time for additional discussion and reflection without increasing the total amount of time spent on teaching duties. Some departments would be able to absorb an extra class for one semester.

V. DATA COLLECTION AND ANALYSIS

The goal of this study was to develop a better understanding of the prospects of co-teaching for promoting instructional change through the in-depth investigation of one semester of co-teaching. This type of study is what Stake refers to as an instrumental case study.[40]

A. The case

In Fall 2005 Henderson was in his fourth year teaching at Western Michigan University. He had been involved in the reform of the introductory calculus-based physics sequence at Western Michigan and had taught both courses in that sequence using reformed methods. He is an experienced PER researcher with knowledge of many PER instructional interventions. Famiano was a new tenure-track faculty member in his first semester at Western Michigan. His prior teaching experience was as a physics teaching assistant while a graduate student at the Ohio State University (OSU). As a graduate student he had some exposure to PER via his interactions with the OSU physics education research group which taught a required quarter-long course for TAs.

B. Data sources

Case study research relies on multiple sources of evidence.[41] A faculty member from the college of education (Beach) was asked to participate in the co-teaching experience. She conducted open-ended individual interviews with Henderson and Famiano at the beginning, middle, and end of the co-teaching semester. Interviews focused on their thoughts about how the course was going, general beliefs about teaching and learning, and perceptions about how the co-teaching was going. A final interview was conducted with Famiano at the end of the Spring 2006 semester after he had taught the course on his own. The associated data sources were the interview transcripts of the seven 45–75 min interviews. Beach also observed Henderson and Famiano teaching, one class session for each instructor at the beginning, middle, and end of the co-teaching semester. The associated data source was the field notes of each of the six observations scaffolded by the Reformed Teaching Observation Protocol (RTOP) course observation rubric.[42,43] This rubric rates teaching activities in five areas (lesson design and implemen-

Table III. Alignment of co-teaching activities within the cognitive apprenticeship framework.

	Modeling	Coaching	Scaffolding	Articulation	Reflection	Exploration
(1) Henderson and Famiano alternate being in charge of class each week.	X	X				X
(2) Weekly meetings between Henderson and Famiano to reflect on previous week and discuss initial plans for coming week.	X	X		X	X	
(3) Course structure set up by Henderson to support PhysTEC design principles.			X			
(4) Famiano had access to materials used by Henderson in previous offerings of the course.			X			
(5) Famiano teaches course on his own during subsequent semester.						X

tation, propositional content knowledge, procedural content knowledge, classroom culture: communicative interactions, and classroom culture: student-instructor relationships) and provides a numerical rating between 0 and 100, where a higher rating represents use of more reformed teaching activities. The other data source was the syllabi used by Henderson and Famiano in Fall 2005 and by Famiano in Spring 2006.

C. Data analysis

Henderson and Beach independently analyzed all of the data sources looking for evidence of Famiano's instructional practices, evidence of Famiano's beliefs about teaching and learning, evidence of Famiano's intentions toward future instruction, and any other evidence related to co-teaching that seemed helpful in understanding the experience. After completing this independent analysis, Henderson and Beach compared notes. There was a large degree of agreement between the two analyses and all disagreement was resolved through discussion.

D. Credibility

Efforts were made to ensure that this study provides an authentic portrait of the co-teaching experience.[43] As Yin suggests, multiple sources of evidence were used and all results are based on the complete set of evidence.[41] The analysis also involved the distinct perspectives of an insider (Henderson) and an outsider (Beach). Although not directly involved in the data analysis, Famiano was asked to review and comment on the results of this study. All of the results reported in this paper have been agreed on by all three authors.

VI. RESULTS

Our goal was to document changes, if any, and degree of agreement with PhysTEC design principles in Famiano's teaching practices, beliefs about teaching and learning, and intentions toward future instruction.

A. Teaching practices

Before the semester started, Beach asked both Henderson and Famiano to talk about how they approach teaching. Both expressed the importance of engaging students in the classroom, but had different ways they saw that happening.

Henderson: "I don't like to do lot of lecturing…I just don't think it's useful for students. I mean they may enjoy it and they expect it but I don't think it really leads to much learning so I do very little of that. I think that the best use of class time is having students think about an idea and I do that by having students work in small groups in class. The hard part of that is just getting students to see that it's a valuable thing."

Famiano: "I am a huge fan of what's called the Socratic method. You lead the student to an understanding by asking him questions or, you know, what many of my students when I TA'd have referred to as throwing it back in their faces by asking them questions. You answer their questions by asking them questions. Allowing them to gain their own understanding is fun. I think it's effective, and a great way for students to appreciate what they are learning at a much deeper level."

In terms of classroom observation both Famiano and Henderson received similar scores on the RTOP instrument for each class session as well as similar scores to one another. All RTOP scores were in the range 89–95. Although these scores are from Beach, who had not received RTOP training, they suggest that both instructors were both working appropriately within the interactive class structure. Beach noticed some more subtle differences, though, in instructional practices. In her first observation of Famiano she wrote "Famiano was somewhat more structured than I saw Henderson to be, but very interactive with students nonetheless. Famiano presented concepts and then problems that exemplified them. Less of having students generate concepts. More formulas." These differences also showed up in certain RTOP items, with Famiano scoring slightly lower on items such as item 4 (This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.) and item 14 (Students were reflective about their learning.).

Both Henderson and Famiano also noticed this difference in instructional practices.

Henderson: "…I do find that he [Famiano] tends to want to tell students more than I would, which isn't surprising, and that he's concerned with the logical order of progression of topics and…I often start with something more complicated and then circle back to [a basic idea] whereas Mike wants to start with, you know, the basics and go above from there."

Famiano: "I noticed Henderson's technique [for managing class discussions] is…slightly different from mine."

Beach: "How so?"

Famiano: "I am not criticizing him at all because this is his technique and it obviously works, but from my point of view, he doesn't mind letting the students hang for a long time and squirm and sweat over this problem. He will ask some, what I consider, very open ended questions whereas I will tend to ask something that I consider slightly more leading."

Although noticeable, Beach considered these differences to be minor compared to the large difference between the co-taught course and other science courses with which she was familiar.

There were no noticeable changes in Famiano's instructional practices during the semester. Pairing this observation with the previous interview excerpt suggests that the scaffolding provided by using a preexisting course structure was effective from the start in helping Famiano teach in a nontraditional way. There was no major "implementation dip"[9] in Famiano's teaching performance.

Although Beach's observations did not indicate any shift in instructional practices during the semester, Famiano's interview at the end of the co-teaching semester indicated that he perceived a shift in his own instruction toward more nontraditional instructional activities. "As the semester wore on what I ended up getting in the habit of…going through the concepts setting up the problem and saying to the students 'you go figure out the algebra on your own'. That allows you to go through many more problems and it also allows you to spend a larger percentage of time on the physics per problem so that they realize that the problem isn't a massive algebraic equation, but it really is physics."

Without the course structure set up by Henderson it is likely that Famiano, much like the new faculty interviewed in Boice's study,[26] would have retained a much more traditional lecture-based instructional style. This likelihood was confirmed by Famiano during the first interview (conducted during the first week of classes when Famiano had participated while Henderson was in charge of the class, but had not yet been in charge himself).

Beach: "If you were doing this by yourself, if they just say "okay, here is your class schedule for the semester. Good luck." What would you be doing? How would you approach preparing for a class like that?"

Famiano: "I would probably not actually in all honesty…not have done it the same way that we are treating this class."

Beach: "Because of?"

Famiano: "I will probably treat it more like a lecture. Of course I tend to be more interactive, so I will still be more interactive, asking the students questions and things. I probably wouldn't do as many in-class activities as we are doing now…and so it will probably be a little bit more like the formal lecture."

The likelihood that Famiano would teach in much more traditional manner without the co-teaching experience was confirmed with a similar question during the final interview with Famiano after the end of Spring 2006.

B. Beliefs about teaching and learning

Statements made by Famiano during the interviews suggest that his beliefs about how students learn were consistent throughout the semester and largely aligned with the beliefs behind the PhysTEC course structure. As a physics graduate student at OSU, Famiano received TA training from the physics education research group which Famiano described as emphasizing the Socratic method and group work. He described developing favorable opinions of both. This exposure to nontraditional instructional techniques likely resulted in an interesting conflict. In Famiano's first interview (prior to the co-teaching experience) he envisioned that his teaching would be some variation of a traditional lecture, yet, he did not think that students would get a lot out of such a lecture. "A student sitting in a lecture listening to you is going to do what most students do, and that is, fall asleep or walk away and not learn something…You have to lead the student to an understanding by asking him questions." This disconnect between beliefs and practices appears to be common in all types of faculty.[44]

Although his beliefs about student learning were consistent throughout the semester, his beliefs about teaching appeared to change. His initial beliefs about teaching were fairly traditional. During the second interview Henderson recalled the first set of lessons that Famiano came to discuss several weeks before the semester had started. They were very traditional in the sense that they called for material to be presented to students in a logical and abstracted sequence. These very traditional plans were replaced with much more innovative plans after the first week of class (for which Henderson was in charge of the class).

Henderson: "I've noticed a dramatic change really [in the approach to teaching taken by Famiano]…Before class even started, he came and talked about how he might approach the topic that he was going to cover in those two weeks and it looked very traditional, 'we will do some equations' and 'we will talk about this' and 'we will do this' and so when the class started…it [what Famiano saw as appropriate instruction] was different."

It is clear from Famiano's second interview that he was initially concerned that the PhysTEC course structure was too much of a departure from the lecture method. "I have really come to appreciate the use of in-class problems. It's surprising to know, because when I first came I was skeptical about having students do nothing but problems in class—just sort of standing by while they do problems. It really seems to be a good method." His largest initial concern appeared to be student resistance to such an interactive class structure. He did not envision that interactive methods would be successful in a large lecture course until he experienced the students being engaged. He was also convinced by a survey of student perceptions of what helped them learn. "What convinced me about this [the PhysTEC course structure] was that most of the students…were really engaged…but even more than that at the end of the semester when we gave them the survey, the thing they liked the most was the in-class work. Very strangely surprisingly to me was that they liked doing this and found it to be very helpful to them." This concern for student opinion was actually a theme that ran throughout all of the interviews and is consistent with Boice's finding that new faculty tend to "teach defensively, so as to avoid public failures at teaching."[45]

C. Intention toward future instruction

Not surprisingly, as Famiano's beliefs about teaching changed, his intentions toward future instruction also began to change. From the first three interviews, it appears that his intentions toward future instruction, specifically the following semester, were changing to become more aligned with a PhysTEC style course. As noted, Famiano was initially skeptical about the course design in which much of the class time had students working together on problems. By the mid-term interview, Famiano was beginning to become comfortable with the course design, but was still largely noncommittal about how these might fit into his future instruction. "You know, it [the co-teaching experience] taught me something that I am going to adopt aspects of in future courses." By the end of term he shifted his perception to be very favorable toward the course structure. "My class [next semester] is going to be very similar to what we did last semester, even the structure will be the same structure. It's going to be almost identical."

In the final interview Henderson still noted differences in their teaching styles, but thought that Famiano's exposure to and practice of the interactive approach they used together would influence Famiano to continue with the PhysTEC course structure. "I think what we're going to find is that Mike is going to teach in the more innovative way than he would have otherwise and in a significantly more innovative way [than many physics faculty in general]."

Even though Famiano indicated at the end of the Fall coteaching experience that his Spring 2006 course would be "almost identical" to the co-taught course, he did make some changes to the course structure. A comparison of the Fall 2005 (co-teaching) and Spring 2006 (Famiano alone) course structure can be found in Tables II and IV. Although the Spring 2006 course appears to be well within the PhysTEC course structure, all changes were toward a more traditional course structure. In addition, almost all changes were made to reduce required faculty time or to reduce perceived student dissatisfaction. For example, by the end of the Fall 2005 semester, Famiano had decided to change the written homework from a group to an individual assignment. This change was largely based on his perception that students did not like

Table IV. Information from course syllabi describing contribution of various course elements toward the final course grade.

Component	Henderson and Famiano course (Fall 2005)	Famiano course (Spring 2006)
Exam average	40% (four exams)	30% (three exams)
Final exam (comprehensive)	20%	20%
Quiz average	15%	15%
Online problems	5%	—
Written problems	5% (group)	20% (individual)
Online exercises	5%	—
Reading assignment	5% (reading questions)	10% (reading quiz)
In-class group work (all members get same score)	5%	5%
Total	100%	100%

the group homework assignments. "It [changing to individual homework] takes out complaints such as 'he doesn't do his share of the work.'" In contrast, although quiz corrections were quite popular with students, Famiano decided not to use quiz corrections in Spring 2006 due primarily to the extra time required for grading.

The final interview at the conclusion of the Spring 2006 semester revealed that Famiano was unhappy with many of the changes that he made and planned to go back to a course structure more closely aligned to the Fall 2005 course. He indicated that his direct experience with co-teaching followed by teaching alone convinced him that the course elements were important enough in promoting student learning that they were worth extra time and possible student dissatisfaction. "I did not do quiz corrections this year, simply because of time constraints involved, and, looking back on that, I think that was a bad idea…I think students looked at quizzes as sort of a module of the course and once you are done with the quiz you are done with learning that material …I'm going to readopt those [quiz corrections and group homework] and, it's going to be extra time involved, but in my mind it's worth it."

VII. DISCUSSION

Co-teaching appears to have been successful in changing Famiano's beliefs and intentions toward instructional practices consistent with the Western Michigan PhysTEC design principles. There did not appear to be any significant changes in instructional practices during the semester, probably due to the predetermined course structure that constrained possible practices. Beliefs about teaching and learning appeared to be largely aligned with the PhysTEC design principles by the middle of the semester, and plans for future teaching continued to change throughout the co-teaching semester and ended being largely PhysTEC compatible. Thus, it appears the entire co-teaching semester was important. It probably would not have been enough, for example, to just co-teach for the first half of the semester.

We hypothesize that there were three important components to the co-teaching design: it lasted the entire semester; the course structure was set up in advance by the experienced instructor; and there was a collegial, cooperative relationship between the co-teachers. It was not a student-teacher or mentor-mentee type of relationship. As Famiano put it, "Well the thing that I liked the most about this is it wasn't like I was Charles' protégé. He recognizes me as a colleague and we were teaching this class together…it wasn't like teacher-apprenticeship which at this level it might seem sort of insulting."

An unexpected, yet valuable outcome of co-teaching was that informal nonteaching related discussions helped Famiano become acculturated to Western Michigan University in areas other than teaching. In reflecting on the co-teaching experience, Famiano commented that "I would ask him [Henderson] everything, not just about teaching…He was actually very helpful in a lot of areas including grant writing…These discussions often sprang from side conversations during the first five minutes before class while waiting for people to mingle in the class." This additional support is frequently lacking for new faculty.[26]

This study of a single case has many limitations that caution against generalization and suggest further work is needed. More examples of similar cases are needed. Famiano began co-teaching with favorable views of and some experience with research-compatible instructional practices. It is not clear that this model would be successful with a new faculty member hostile to research-based instruction. It is also likely that the personalities and other personal characteristics of the co-teaching participants must at least be somewhat compatible for co-teaching to be effective.

Other interesting questions for future work would be to examine the applicability of co-teaching for other populations. Famiano was a new faculty member. Would co-teaching work similarly with an experienced faculty member who had already established a strong traditional teaching routine? Would the co-teaching model be a useful way for graduate students to develop teaching expertise?[46]

VIII. CONCLUSIONS

Co-teaching is a cost-effective model that shows significant promise as an effective way to promote research-consistent instruction in new faculty. It is rooted in an apprenticeship instructional paradigm. It is effective because it immerses the new instructor in a teaching role in the new instructional context and provides scaffolding and modeling to ensure success.

Co-teaching is only appropriate when there is a teacher available who is experienced in teaching the target course in a research-consistent manner. Thus, co-teaching cannot be expected to replace traditional dissemination methods. When the conditions are right, co-teaching appears quite powerful and should not be overlooked. With the expanding presence of PER researchers/teachers in physics departments, it could have a significant impact.

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