Perspectives of Pedagogical Change within a Broadcast STEM Course

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Abstract

As calls for pedagogical transformation of undergraduate science, technology, engineering, and mathematics (STEM) instruction intensify, the pace of change remains slow. The literature shows that research-based instructional strategies transfer only sporadically into STEM instructional practice. Difficulties associated with implementation and sustainment of instructional change may appear daunting— if not insurmountable—to many STEM change agents and teaching faculty. Subsequently, the path towards systematic and lasting pedagogical transformation in post-secondary STEM stands largely uncharted.

To understand how challenges faced by STEM educators engaged in pedagogical change may be overcome, this paper uses qualitative inquiry to explore an emergent process of teacher change. The change process took place during implementation of an online innovation within an undergraduate engineering calculus course taught via synchronous broadcast at a mid-size, Western, public university. The instructional innovation required first year calculus students to participate in an asynchronous, online discussion forum for graded credit. Data, consisting of written reflections and transcribed interviews, were gathered from three STEM faculty members who each played a different role in the change process: a mathematics instructor implementing the online forum within his course; an engineering faculty peer-mentor assisting with the implementation of the online forum; and a STEM education faculty member evaluating the implementation and observing the process of change. Situated within the interpretive research paradigm, this study uses exploratory thematic analysis of narrative data to understand the ways in which contextual factors may influence pedagogical change.

Introduction

Amid increasing calls for science, technology, engineering, and mathematics (STEM) pedagogical transformation[1, 24] and growing concerns over the lack of transfer of research-based instructional strategies to STEM[23, 24] classrooms, several scholars[2,3,12] advocate for a deeper understanding of instructional change within STEM disciplines. Henderson et al.[12] summarized the situation saying, "the state of change strategies and the study of changes strategies are weak and …research communities that study and enact change are largely isolated from one-another" (p. 1). Borrego and Henderson[3] suggested that efforts toward pedagogical change in STEM remain unsystematic and that STEM fields have not, as yet, developed an understanding of how and when to implement the variety of change approaches now documented within the research literature (pp. 222-223). Therefore, the current state of the instructional change literature in STEM indicates a need for more exploratory work and provides impetus for this study.

Background to the Study

This qualitative study concerning STEM instructional change emerged from a larger, three-year study funded by the National Science Foundation (NSF) Transforming Undergraduate Education in STEM (TUES) program titled "Online learning Forums for Improved Engineering

Student Outcomes in Calculus"[21, 22]. The purpose of the TUES study is to explore use of online learning forums to improve student achievement and engagement in STEM courses. The TUES project plan requires the principal investigator (PI) to assist a mathematics instructor (MI) in implementing an asynchronous, online learning forum within distance-education calculus courses taught via synchronous broadcast. In synchronous broadcast course delivery, a single faculty member simultaneously instructs students located in the same room and other, geographically dispersed students located throughout the state at several regional campuses. Real-time instruction is provided to all students via two-way audio/video conferencing[22]. During the TUES project, the research team gathers mixed-method data to assess achievement and affective outcomes among students who did and did not have access to the online intervention.

As the TUES project recently moved into its third year, the members of the research team noted a process of teacher change occurring as a result of project activities. Periodic reflective interviews with the MI, as well as informal discussions in research team meetings, suggested that the MI is doing more than simply implementing a prescribed instructional innovation. Rather, the research team witnessed as the MI moved from a state of reluctance to one of enthusiastic adoption of the online intervention. Sensing this deep attitudinal shift on the part of the MI, the research team pursued the current qualitative study in order to explore an emergent process of pedagogical change in STEM.

Literature Review

Henderson et al.[12] discussed three distinct research communities involved in understanding how to facilitate pedagogical change in higher education: STEM education researchers (SERs), faculty development researchers (FDRs), and higher education researchers (HERs) (pp. 3-4). Most commonly, SERs are located in STEM disciplinary departments, such as in colleges of arts and sciences or engineering, or in colleges of education serving as STEM specialists[15]. Based upon this characterization of the SER community, the SER literature is considered most relevant to the present study.

Henderson et al.[15] found that the SER instructional literature preferences instructional change conducted by individual faculty members in a prescribed manner:

> In the SER community, the dominant approach to change is that of development and dissemination…. Conducting education research and developing new curricular materials requires considerable time and expertise that STEM faculty typically do not possess. Therefore the development task is delegated to a small number of individuals and the 'finished products' are given to other faculty for implementation. The assumption is that the faculty will be convinced to use these new instructional materials and strategies once they are shown data demonstrating improved student learning. (pp. 18-19)

Henderson et al.[15] also pointed to fallacies embedded within this highly prescribed and individualistic approach: a lack of a "meaningful role for typical faculty to play in the change," and a failure to account for the "environments and structures that [STEM] faculty work within, which typically favor traditional [teacher-centered] instruction" (p. 19). For example, Henderson and Dancy[14] found that, while physics faculty members generally agreed with educational researchers concerning the nature of proposed interventions, the faculty resisted direct implementation of interventions prescribed by the researchers. Instead, faculty frequently "reinvented" the interventions to fit their particular learning environments and teaching practices prior to implementation (p. 81).

Henderson and Dancy[13] found that physics faculty often blamed situational factors for impeding or preventing their adoption of instructional innovations and that faculty desired more innovations tailored to their specific contexts. Several situational factors, including expectations for content coverage, lack of instructor time, departmental norms and culture, student resistance, class size, classroom layout, and the structure of fixed semester lengths were found to contribute to differences between the teaching conceptions and practices of the faculty[13] (p. 9). Other scholars[6,11] reported that faculty time constraints, due largely to "…multiple, competing role expectations…"[11] (p. 40), act as a significant barrier to pedagogical change. Hearne et al.[11] depicted how the use of technology facilitated pedagogical change in the redesign of an introductory chemistry course by " address[ing] time constraints and role overload" for the STEM faculty involved (pp. 56-57).

Butler, Marsh, Slavinsky, and Baraniuk[4] proposed that significant barriers to innovation due to course sequencing requirements and resource constraints impact the ability of individual STEM faculty to adopt interventions long-term. Butler et al.[4] provided quasi-experimental evidence that "simple" interventions (that can be employed by faculty without tripping the barriers) based upon available information and machine technology and common principles of cognitive science improved student learning in an undergraduate electrical and computer engineering class (p. 331). They used this evidence to argue for instructional innovations that are generalizable rather than discipline specific, scalable rather than comprehensive, and easy to implement rather than resource-intensive (p. 332).

While Seymour[25] acknowledged that evidence of improved student learning (e.g., Butler et al.[4]) is commonly considered a "necessary condition" for transfer of research-based instructional innovations to practice in STEM, she suggested that this evidence may not, of itself, be "sufficient" when considering the adoption decisions of individual STEM faculty members (p. 98). Seymour[25] stated,

> Although proof of efficacy for well-developed classroom innovations is needed for them to be taken seriously, this does not, in and of itself, prompt colleagues to take note of the evidence or see it as a valid reason for change in their own professional practice…. When the shift that is called for is a shift in values and social behavior (rather than in disciplinary thought and practice) the response…is often unaffected by available evidence…. the personal endorsement of classroom innovations by colleagues who are esteemed for their research, and/or for their institutional prestige, is more important than reading or hearing accounts of evidence" (p. 99).

Seymour[25] emphasized the need to explore how professional networking affects dissemination of innovations and to understand why "some faculty decide not to pursue an initial interest in any innovation and others reject it outright, and what contextual factors make it difficult for others to remain active" (p. 92). Seymour[25] also suggested that the exploration of examples of pedagogical "adapters" or "converts" would be worthwhile (p. 92).

Research Question

To explore an emergent process of STEM teacher change, this study was guided by the following research question: How do contextual factors influence pedagogical change during implementation of an online innovation in a synchronous broadcast Calculus I course?

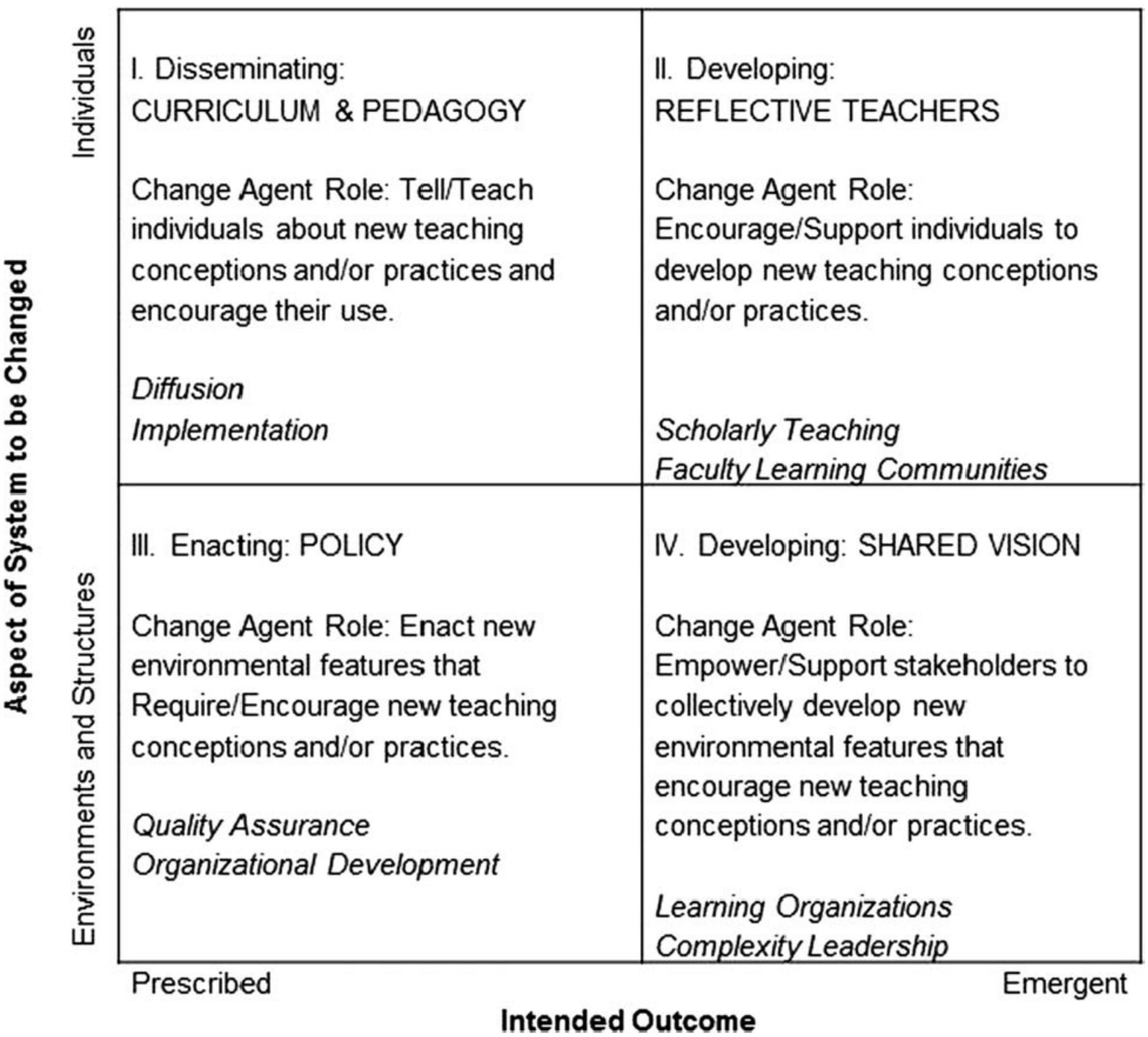

Figure 1 © ASEE, 2014. Common STEM change strategies (shown in italics at the bottom of each category) mapped to the four categories of change strategies model. Figure reprinted from Borrego and Henderson[3] with permission.

Conceptual Framework

Based upon extensive review of 191 journal articles from the STEM higher education literature published between 1995-2008, Henderson and colleagues[2, 12] proposed a framework, known as the the Four Categories of Change Strategies model (Figure 1), to describe and categorize STEM instructional change processes. This model is used as a conceptual framework for the process of teacher change presented in this study. As Borrego and Henderson[3] suggest, we use this model to situate the emergent change process within the larger landscape of instructional change and to connect our findings with the literature related to pedagogical change within other STEM disciplines. Doing so helps to "…articulate the underlying logic and assumptions…[and] support the eventual development of [STEM change] theory"[3] (p. 223).

Specifically, we frame our study on change categories (each category is shown as a square in Figure 1) that seek to change individuals (i.e., categories I and II) rather than larger structures or environments. Strategies that focus on individual change include dissemination of curriculum and pedagogy (e.g., diffusion, implementation) and development of reflective teachers (e.g. scholarly teaching, faculty learning communities) and correspond to the top half of Figure 1. For the purposes of this study, the specific strategies of implementation (category I) and scholarly teaching (category II) are most relevant.

Implementation is described as "as set of purposeful activities…designed to put proven innovations into practice in a new setting"[3] (p. 226). A key metaphor for implementation is "training" and the common metric used to judge the success of implementation is "fidelity" in the continued use of the innovation[3] (p. 226). The outcomes of implementation are prescribed because the innovation to be implemented must be known a priori. Scholarly teaching is described as efforts taken by individual faculty to "…reflect critically on their teaching in an effort to improve." A key metaphor for scholarly teaching is "self-reflection" and the common metric used to judge its success is "self-reported changes in beliefs, teaching practices, or satisfaction with student learning"[3] (p. 226).

The four categories of change strategies (Figure 1) are organized in relation to each other based upon two criteria: the level at which the proposed change takes effect (environment, structures, or individuals) and whether the intended outcome of the change is known in advance (prescribed) or is dependent on the change process itself (emergent). Borrego and Henderson[3] note that actual instructional change efforts "… can and perhaps should…" involve more than one category of change strategy (p. 223). Thus, these categories can be seen as overlapping and may be mutually supportive. Moreover, the use of precise combinations of change strategies may be "particularly powerful" although evidence is needed to substantiate this claim[3] (p. 243).

Methodology

In this qualitative study, the research team adopted an interpretive theoretical perspective[10, 17, 18, 19] by openly assuming that humans "…experience the world…in different ways"[17] (p. 152). This perspective encouraged deep exploration of a single process of change from multiple personal, situated perspectives. The team employed a narrative research methodology[5, 7] to explore these personal experiences as communicated in narrative form by participants who were directly involved in the implementation of the online forum innovation. As Creswell[7] explains, narrative inquiry "begins with experiences as expressed in lived and told stories of individuals" (p. 70). Thus, narrative accounts of the process of change uniquely serve our research purposes.

Participants. The participants for this study were purposefully selected from the TUES project team as those most closely involved in the implementation of the online intervention in Calculus I: the MI, the PI, and the project external evaluator. The MI is a teaching faculty member in the mathematics department, located in the college of science. He has instructed mathematics (through calculus) at the post secondary level for eighteen years. He has taught via synchronous broadcast delivery within the university's distance education program since 2003. The PI is a professionally licensed mechanical engineer who is now a teaching faculty member in the engineering college. She has instructed first and second year undergraduate engineering courses via distance delivery methods within the distance education program since 2009. The evaluator is a professor in the School of Teacher Education and Leadership, located within the education college, who specializes in mathematics education and program evaluation. He has experience investigating and evaluating pedagogical change in STEM education that extends over twenty-five years which includes over thirty state, national, and international initiatives.

Methods. The idea for an exploration of the MI's experience in Calculus I, as an example of emergent teacher change, bubbled up organically from within the TUES research team during a regularly scheduled team meeting. The team observed the MI move from a state of anxiety and reluctance concerning use of the online innovation to one of enthusiastic adoption where he is now excited about and committed to using the innovation in his future courses. This notable change in the attitude of the MI sparked a mutual interest among the team members in performing this study.

The data collection process itself was emergent since it evolved based upon the needs and preferences of the participants. The TUES PI took the lead in the data collection and requested that each participant (the MI, the PI herself, and the evaluator) write a personal, reflective narrative describing her experience during the implementation of the online intervention in Calculus I. The PI chose written, narrative accounts in order to encourage deep personal reflection, to capture appropriate detail, and to insure highly individualized accounts of the change experience. To support data taking, the team jointly crafted a list of guiding questions to facilitate individual reflection during the narrative writing:

1. Describe your role in this experience.
2. What are your previous experiences with and/or attitudes toward pedagogical change in STEM?
3. Describe your general experience during the implementation of the online forum (e.g. likes, dislikes, surprises, frustrations, limitations, things to improve…)
4. How has this experience changed the way the instructor does his job? Consider how the following aspects of the instructor's job may /may not have changed:
    a. Instructor use of classroom time
    b. Preparation outside of class
    c. Helping students both during and outside of class

    d. Classroom student experience
    e. Student performance
    f. Student interaction
    g. Student engagement
    h. Instructor/student interaction
    i. Student satisfaction with their learning
5. What have you learned about pedagogical change from this experience?

As each narrative account was (individually) written, it was sent in electronic form via email to a professor of qualitative research and multicultural education (who is not affiliated with the TUES project) in the college of education at our university. She read the initial narratives and provided written feedback, asking questions and highlighting areas within the narratives where further reflection was needed. She continued to act as a "peer debriefer"[8] (p. 202) throughout the study by reviewing and asking questions of each narrative account so that the findings coming from these narratives would "resonate" beyond our research team[8] (p. 202).

Upon reviewing and discussing the initial narratives with the peer debriefer, the PI met with the other participants and requested that they continue to reflect on their experience and provide more data in written, narrative form. The evaluator agreed to provide more written data concerning his initial expectations as the TUES project evaluator and how these expectations changed based on close interaction with the mathematics instructor during the implementation of the intervention in Calculus I. It was at this point that the MI confided that the exercise of writing the first narrative had been particularly stressful for him. The MI explained that it was much easier for him to talk about, rather than to write about, his experiences. The PI offered, and the MI agreed, to conduct an interview in order to delve more deeply into the instructor's experience without adding to his anxiety level.

A few days later, the PI conducted an in-depth (92 minute) interview with the MI at a location selected by the MI. The format of the interview was "informal" and "unstructured"[16]. In an "unstructured" interview, the interviewer does not use a list of questions or interview guide. Rather, the interviewer follows the participant in a discussion, seeking only to maintain the overall topic of the discussion[16]. The PI chose this unstructured format because it most closely matched the initial writing approach to gathering the reflective data. The interview topic was the instructor's change in attitude relative to the intervention and how that change occurred. The interview was audio recorded and later transcribed into written form by a professional transcriber. The PI confirmed the accuracy of the transcript prior to analyzing the data.

Analysis. The PI conducted an exploratory thematic analysis of the written reflections and the verified, transcribed interview data. The PI performed two coding passes using dedoos qualitative analysis software[26]. The first pass employed a hierarchical code structure in which the codes were taken directly from the four categories of change strategies conceptual framework (Figure 1). The second coding pass employed codes that emerged directly from the data. The coded data was then grouped into major themes. Recognizing the ways in which the codes from each of the two passes grouped on individual data excerpts facilitated the process of developing themes from the coded data. The themes were brought back to the other participants for "member-checking"[8] (p. 201) and revision. The resultant themes are presented as findings.

Limitations of the study. This exploratory, qualitative study lacks broad generalizability due to its highly contextual, situated nature and small sample size. Small sample sizes are often characteristic of qualitative research because they allow for in-depth, detailed data collection. Qualitative researchers do not claim that small samples represent the population of interest—in this case STEM faculty engaged in pedagogical innovation. Rather, purposeful sampling of a small number of participants is used in exploratory, qualitative research to select the participants that "…will best help the researcher understand the problem and answer the research questions"[8] (p. 189). A second limitation is the reflective nature of the data. As the participants reflected on their experiences concerning implementation of the online intervention, uncertainty exists as to whether their retrospective descriptions match those that would have been provided during the actual implementation. Methodological emphasis on data triangulation by "converging" the perspectives of participants from different STEM backgrounds and member checking research findings help to mitigate this limitation and add validity to the study[8] (p. 201).

Findings and Discussion

Describing the emergent process of change: a case of overlapping strategies. As suggested by Borrego and Henderson[3], the four categories of change strategies model (Figure 1) can be used as a tool within the SER community to describe real, inherently complex processes of pedagogical change using a common language (p. 223). In situating the process of pedagogical change depicted in this study, the strategy for change is described as a category I implementation strategy. The aspect of the system to be changed was at the level of the individual instructor and the method of change —the intervention, a freely available online learning forum (www.piazza.com)— was prescribed. The PI, who had previous experience using the intervention in her undergraduate engineering courses, was responsible for training, coaching, and monitoring the progress of the MI as he employed the online learning forum within his Calculus I course. The success of implementation strategy was considered to be the continued use of the innovation by the MI (i.e., long term adoption).

The reflections of the PI and evaluator underscored their understanding of the change strategy to be that of implementation of a prescribed innovation. The PI used the words "implement" or "implementation" sixteen times in her written reflection and described that her " role in the implementation of online learning forums in calculus is that of a mentor to … the calculus lecturer." She described herself as feeling "excited" and "grateful" that the MI was "willing to try something new and allow us into his classroom." Later, she discussed how, as the use of the online forum in Calculus I loomed larger, she became "frustrated" at the amount of help with learning and implementing the forum that the MI wanted. She remarked that "the other members of the research team themselves seemed to grow a little nervous, wondering if MI would embrace the tool in time for the treatment section. I think we were all feeling some pressure at this point." Thinking back, she said that it was when she consciously began acting as "more of a mentor (and less as a PI)" that the MI began to progress in terms of learning the tool and thoughtfully considering its implementation.

The evaluator described his interest at the beginning of the TUES program regarding "…how implementation of social media programs would influence how and in what ways students learn." He commented that he "viewed Piazza [the online invention] as being a relatively easy innovation to implement—somewhat independent of any influence of the instructor." The evaluator went on to say that he had considered the MI to be a "perfect instructor in a controlled experiment focused on student change" where the MI's "reticence towards technology in many forms (e.g. cell phones, instructional software), confidence in the routines of mathematics, and perceived approach to teaching and learning (seemingly entrenched and unlikely to change to any great extent), appeared ideal for a study where minimizing teacher effect would be important." Together, the reflections of the PI and evaluator indicate that the use of the online intervention in Calculus I was initially understood to be a process of implementation of a prescribed innovation.

In analyzing the data from the perspective of the MI, however, it became apparent that another, perhaps overlapping change strategy— that of scholarly reflection (i.e., Figure 1, Category II: Developing reflective teachers)— contributed in important ways to the positive, lasting change outcome. In his initial written reflection, the MI described his personal attitudes toward pedagogical change: "I am certainly open to pedagogical change, as long as it is of some benefit to my students. I have no interest in change for its own sake." Later (in the interview) when asked about his prior experience with pedagogical innovation, he discussed how he had initially considered and then reconsidered use of graphing calculators saying, "I'm always somewhat skeptical about technology. Even when graphing calculators first came out, I was skeptical about those, believe it or not. We don't need that – we've done fine without it. Of course I've embraced that because I see the value."

It was in this process of "seeing the value" where scholarly reflection seems to have been an important part of the change process for the MI. The MI went on to describe another instructional change he has recently experienced-— posting his class notes:

MI: Well okay, so it's like this – not that long ago I was reluctant to post my class notes [online] just because I felt like note taking was a skill that students should develop. Now I post class notes to all my classes.

PI: Okay, why?

MI: Well it's the trend, isn't it? To make things as easy as possible for the students – Is that good?

PI: So were you – what made you start to post your notes? Was it people complaining? Was it people asking?

MI: Well they asked, yeah – they asked. Then I started thinking about what a wretched note taker I was as a student. I thought well if I'd been able to go and look at the professor's notes, that might have been good— that might have helped me. So I could see value in doing that, so I do.

It was his "thinking" and reflecting back on his personal experiences as a mathematics student that motivated the MI to make this small but lasting change.

An important difference between a small change, such as posting class notes, and a larger one, such as implementing an online learning forum, is one of complexity. Posting class notes is a single step process that, although takes some time, is straightforward to learn how to do. Perhaps one needs to be shown how to do it once. Implementing an online forum, even though it may be packaged in an "intuitive" or easy to use online tool, requires considerably more effort to learn and design into one's courses. Understandably, one would want to have help in setting up the tool in the course, in discussing how to introduce it to the class, and in practicing to use its features. Thus, when the MI described his adoption of the online forum, the overlapping nature of two change strategies-—scholarly reflection on the value of the change and implementation under the guidance of a mentor — became evident. The MI explained,

> …It's [the online forum] something that I was reluctant, or at least fearful of. Once I did it I saw it wasn't all that bad and I see the value in it. So that's perfect – those sorts of things, that's what I'm looking for. Maybe not actively looking for, but if they come along, I'm open to them, more so now than I was before. Yeah, I'm still not excited about a Smartphone or anything, that's not going to happen, but I don't see any reason to do that. Whereas this [the online forum], now I see it's the right thing to do, so I must do it.

When asked how his experience preparing for Calculus I with the PI helped or made it harder to employ the online forum, the MI replied:

> MI: Well again, my starting point was probably a lot lower – most people would have started with a certain degree of comfort probably with that sort of thing just because most people are on their Smartphones two to three hours a day, right, and I'm not. So any sort of technological advance or tool for me was a big step.
>
> PI: So just the fact that it had to do with technology brought with it…
>
> MI: A certain degree of fear – yeah, because I'm not familiar like most people are…. So for most people that are technologically savvy, as I like to say, then adopting Piazza [the online forum] would probably not be that terribly bad, because it wasn't, really, once I saw here's all you got to do.
>
> PI: So it took having to see it?
>
> MI: Oh yeah, and you walking me through things and holding my hand…. So I was starting at a much lower level and even with that, it wasn't terribly bad once I actually put my hands on it and started doing it.

The MI went on explain why he now feels that use of the online forum is "the right thing to do":

> MI: I mean we're in a very – it's not unique, but in an unusual position with our method of delivery [synchronous broadcast]. In the sense that it's not a – all our students aren't sitting right in front of us, we've got people all over the

place…Yeah, and it's a miracle and it's wonderful because it allows people in very remote places, that couldn't otherwise get a college education, to do just that and I think that's wonderful. But it's not easy, so I guess…

PI: From either perspective, right.

MI: Yeah, and to make it fair for all those students that are at other sites, to the students that aren't right in front of us, to make it as fair as possible. Then you've got to communicate – everybody has to have that same opportunity to communicate with me.

PI: So you see, in this distributed system that we have – so do you feel that there's a – do you feel it's unfair?

MI: Well certainly in my classes up to this point, it has been, yeah sure because inevitably the students that are [physically] right in front of me, in my face-to-face section, they're going to get more attention than the students at the other sites. They're going to be able to reach me and ask me questions and talk to me much more easily and that puts the students at the other sites at a disadvantage, I mean I believe…. So, there it is. I was like well, Piazza … but it actually makes things more fair for students that are at a distance – the remote sites. That is just the right thing to do for our method of delivery. I mean if it was a face-to-face section, it might not be as important to me. But with people scattered all over the place, you got to think about all your students, not just the ones sitting right in front of you, inevitably they're going to get more of your attention.

From this series of excerpts it appears that scholarly reflection (category II) is the MI's first or primary change strategy. However, the complexity of the online intervention became a critical factor for the MI. To use the online forum, the MI needed overlapping change strategies—mentorship on the use and application of the innovation (category I implementation) in addition to scholarly reflection (category II) on the value of the innovation — in order to overcome his initial fear and anxiety. This example may indicate that pedagogical change can be initiated through internal, reflective strategies (category II) involving an instructor's personal value discernment and costs vs. benefits analyses. External, dissemination-style strategies (category I) may be useful as overlapping or assistive strategies as the complexity of the interventions increase.

Resultant themes related to pedagogical change.

Technology as a potential barrier to pedagogical change. Technology, or the level of technological complexity of a pedagogical innovation, is not listed as a common barrier to pedagogical change in the STEM literature reviewed for this study[11, 13,14,15]. Moreover, Butler et al.[4] reported that automation in the form of an online tutor system was a factor that promoted a positive change outcome. The MI in this study, however, seemed to view technology as a contextual factor that made innovation more difficult; it was hard for the MI to gauge the potential value of the innovation (perhaps due to his inherent skepticism and infrequent use of personal technology) and to learn to use the innovation (perhaps due to having limited experience with web-based tools).

The MI described himself as "always somewhat skeptical about technology," not "technologically savvy," and "starting at a lower point" than others who are more interested in using technology in their everyday lives. At one point in the interview he remarked that "there were times when I was like, she's [the PI] got the wrong person for this [online forum implementation]." The evaluator noted the MI's "reticence toward technology in many forms (e.g., cell phone, instructional software)." While such attitudes towards technology may be in the minority of popular opinion now and in the future, the current pace of technological innovation makes it important to consider technology as a potential barrier to pedagogical change. It is not possible to suggest that a large or even significant portion of STEM faculty share this skepticism of technology based on an interview with only one STEM faculty member. Nevertheless, it may be important for members of the SER community to recognize that the technological complexity can impede attempts of some STEM faculty to implement change. Thus, it seems wise to consider the ways in which the STEM faculty who are targeted for change view technology both personally and in a classroom setting.

The importance of matching the intervention to the learning context. The MI made the point that a significant portion of his enthusiasm and motivation for adopting the online forum came when he realized that the tool helped to improve an inherent problem of the geographically disbursed, synchronous broadcast learning environment in which he taught Calculus I: unequal access to communication with the instructor and other students between the sites. The instructor explained that students that happened to take the course from the site where he taught had an advantage in terms of opportunities to ask questions and to discuss the material.

MI: I think it's [the online forum] a worthwhile tool now because – well, once I'd been using it for a few weeks in the Calc I section especially, it was like okay. I'm interacting with students from [all of the sites] and I wouldn't probably have done that without it. I mean certainly they [the students] could send me emails, but those were pretty rare and it was a real awkward thing. …

PI: Okay, so you changed from being skeptical and fearful to feeling like if you don't do it [use the online forum] then you're not treating everybody fairly?

MI: Yeah, it's the right thing to do…. My … students [who are physically in the class with me] – they can walk into my office and ask me a question or they can ask me a question after class, which they often do. A student from …[another site], they can't do that, it's just physically impossible. So in terms of access, it's helpful. Well now – see the problem is now in my other [synchronous broadcast] classes I feel like it's just not fair.

The MI further discussed how he may not have been as enthusiastic about the online intervention if he taught in a traditional face-to-face environment because, as he said, "they [the students in a face-to-face class] all have the same opportunity [to communicate, to access the instructor] and the motivation is not nearly so strong and its like posting my notes or—which maybe it helps or maybe not…" In many ways the online forum appears to have been the right tool for the Calculus I course because of the distance-learning environment in which it was taught.

Later in the interview, the MI discussed how the online forum enabled him to effectively answer complex mathematical questions outside of class and this meant that considerably fewer questions were asked in class. This outcome was important to him because, in Calculus I, covering required content is a real challenge. In fact, the MI struggled to cover the required content in the control section of Calculus I (when the online forum was not implemented). Use of the online forum, in essence, gave the MI back some class time normally spent answering questions from the previous material. The following excerpt describes this benefit.

> MI: Well because in like a Calculus class, if you don't cover it then you're going to pay because something's going to come up in the next class, they're supposed to know this. So when I skipped over the method of cylindrical shells I did that because I'd gone through and I'd looked. It's like, okay this topic is not really touched on in subsequent sections, except very rarely.
>
> PI: When did you do that?
>
> MI: That was the control sections of Calculus I. I just ran out of time. So the one thing about [the online forum] in terms of the class is that it does free up a little bit of class time because questions are handled mostly outside class…. So that's really nice and for me personally, that's another – perhaps the most useful perk for Piazza [the online forum], is because it does free up the class time, even if it's like I said, ten to 30 minutes per week, that's real. That's real.

Thus, the nature of the subject (i.e., calculus) is seen as another contextual factor that played into the mathematic instructor's motivation for adopting the intervention long term.

What kind of evidence is necessary to promote innovation? This study raises questions concerning the nature of evidence needed to motivate STEM faculty to attempt and adopt pedagogical innovations long-term. While Seymour[25] discussed how "proof of efficacy" is needed in order for any pedagogical innovation "to be taken seriously," she also noted that this sort of proof does not, by itself, "prompt colleagues to take note of the evidence or to see it as a valid reason to change their own professional practice" (p. 99). As caveats to the theory that evidence of improved student outcomes must be provided in order to effectively disseminate an innovation, Seymour[25] proposed that a) skeptics and interested inquirers alike must be able to make sense of the data, b) data must illuminate outcomes that are valued by the targeted audience, and c) personal endorsement of new teaching practices, and/or evidence in their favor, by colleagues with high research prestige may be required (p. 99).

The data provide insight into the kinds of evidence needed to motivate and support pedagogical change. As it happened, the Calculus I students in the treatment section (where the online forum was available) did not perform better on course exams than the students in the control section (where the online forum was not available). Knowing this, the MI was asked how this lack of evidence of improved student learning affected his decision to adopt the online forum in the long-term:

PI: Okay, what if I told you that the data shows – well you know, the data [from the TUES study] doesn't support that it [the online forum] helped their achievement scores. Do you still feel compelled to use it?

MI: Sure, yeah, yeah – because again, it's an equity issue, what's fair? …It's not going to be equally fair for everyone, but it's a step in the right direction, we have to do all we can do. That's why I feel compelled to do this… that'll make it more fair for everybody and it'll keep the students more engaged.

The MI remained confident in his decision to use the innovation long-term despite a lack of proof of learning gains by his students. His commitment may be related to his positive experience with the online tool and seeing the more subtle benefits it offers first-hand. Importantly, he showed understanding of the pitfalls to obtaining evidence of improved student achievement during the early "period of classroom adjustment" that occurs when an innovation is introduced into a new classroom setting and the difficulty of seeing learning improvement the first few times an innovation is used[25] (p. 98).

PI: So if you had to rate this whole experience [of using the online forum in Calculus I], one to ten, what would you rate it?

MI: Pretty highly – with ten being the best, right?

Q: Yeah…

A: I'd say an eight.

Q: An eight?

A: Yeah, I'd say an eight. I mean I would love to have seen dramatic increases in performance on exams, but you know, realistically we shouldn't even expect that, especially the first semester that they're using it…. But for me personally, yeah it's been a good experience. It's given me a tool that I feel is useful and important and has opened – it's made me more open to further changes, which is a good thing. Probably hasn't made me any less lazy or fearful, but there it is.

Thus when considering the types of evidence needed to promote pedagogical change and innovation, it appears that even subtle changes in the classroom dynamic, or the "gut instinct"[14] (p. 87) of the instructor about what is right to do in certain classroom situations may have substantial impact on an instructor's decision to pursue pedagogical change long-term.

Conclusions

In this study, we have presented a qualitative exploration of an emergent process of post-secondary teacher change occurring within a distance-delivered, first-year calculus course. In situating this case of pedagogical innovation within the four categories of change strategies framework [2,3,12], we have attempted to clearly communicate our assumptions and interpretations of the data in order to connect our findings concerning instructional change to the broader conservation in STEM.

We have presented case evidence suggesting that synergy may occur when combining the dissemination strategy of implementation and the development strategy of scholarly reflection/teaching. In this study, the MI initially relied solely on scholarly reflection to motivate change. As the innovations became more complex, his need for mentoring and coaching—such as can be provided by an implementation style change strategy—grew. Ultimately, a combined approach consisting of scholarly reflection and coaching by a colleague—mentor proved effective in facilitating more complex change with lasting outcomes.

While we present a singular case of individual teacher change, we note the encouraging words of Borrego and Henderson[3]: "Small scale changes and incremental improvements are important steps toward long-term goals of changing undergraduate STEM instruction for the better" (p. 245). With this study, we hope that we have contributed in some small way to the larger, on-going efforts to change instruction in STEM education.

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