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Collaborating on Inquiry-Based Mathematics Education Curricula with Graduate Student Instructors to Establish an Equitable and Sustainable Community of Practice

Josh Brummer , Sean Yee, and Nathan Wakefield

ABSTRACT

We present a multiple case study wherein one institution established new communities of practice supporting graduate student instructors teaching coordinated courses in the presence of minimal existing resources and funding. This was accomplished by partnering with and adapting resources from another institution; one with a well-established community-driven curriculum structure. In particular, we detail a potential model for similarly seeding a new community of practice by describing amounts of time and attention for adapting curriculum materials. We also detail how a professional learning community approach can be leveraged to build curriculum structures that can sustain an equitable community among instructors.

KEYWORDS

Community of practice; professional learning community; graduate student instructor; inquiry-based mathematics education; curriculum reform

1. INTRODUCTION

Similar to primary and secondary preservice teachers, graduate students in the United States need support transitioning to full instructors of undergraduate courses [3]. Graduate student instructors (GSIs) are graduate students who are full instructors of record for undergraduate mathematics courses, a role that represents a level of teaching responsibility beyond that of a teaching assistant which many graduate students experience for just the first or second time in their professional teaching career. GSIs are responsible for teaching hundreds of thousands of undergraduate students each semester [1]. As a result, their pedagogical education, resources, and support are paramount to mathematics departments' well-being [3].

1.1. Problem Statement

With so many expectations on GSIs as students and teachers, carefully organized and flexible support for GSI teaching is critical. Many institutions have undertaken efforts to provide such support. However, GSI development varies significantly depending on the university, undergraduate population and resources of the university [15]. Nationally, the Mathematical Association of America (MAA)

has released the Instructional Practices Guide (IPG) illustrating evidence-based, student-centered best teaching practices for undergraduate mathematics. At the same time, the international mathematics education community has started emphasizing how the ideas of the IPG fall into the larger frame of Inquiry-Based Mathematics Education (IBME) [8], which synergizes inquiry-based learning and inquiry-oriented instruction. Both the IPG and IBME put the focus squarely on student learning rather than teacher performance, resulting in an emphasis on *active learning*, where students are actively engaged in content rather than passively receiving content. For new GSIs who are just learning the basics of teaching mathematics, the IPG and IBME can seem daunting and out of reach. Thus teaching expectations for new GSIs have been raised to a threshold that is challenging to GSIs and departments who want to encourage best teaching practices.

Calls for implementing student-centered practices including IBME have become commonplace in mathematics education literature. Perhaps one of the strongest claims is the oft-cited Freeman report which called for STEM instructors to “begin to question the continued use of traditional lecturing in everyday practices [5].” However, enacting and sustaining change is notoriously hard; a significant shift in culture is likely needed, and institutional norms are deeply ingrained and often impede changes to teaching [12].

In their work on department change, Shadle, Marker, and Earl identified 18 ways to categorize barriers to institutional change regarding teaching norms [12]. Among these barriers, three are particularly relevant to this study. Two of the three barriers are closely connected: inadequate resources and time constraints; teachers note that they are often over-committed and do not feel they have the time to develop new materials. In many university settings, the resources are not available to build an entire curriculum. The third relevant barrier relates to culture, specifically, the absence of a culture that supports and rewards innovative teaching.

One way of addressing all three barriers is to create and support an appropriate collaborative knowledge and community structure, and in this paper, we detail a process by which this may be accomplished (which hopefully serves as a helpful reference point for others who wish to catalyze change). In particular, fostering a community of practice among GSIs is one way to help them manage the knowledge structures and expectations around teaching, thus contributing to a more supportive culture. The problem our work strives to address is how to build and support a community among GSIs; one that generates and sustains materials that will help all GSIs (especially novice GSIs) avoid reinventing the pedagogical wheel, while also providing allowance for time and resources to focus on student engagement in an active learning classroom. This can be challenging to address due to the variability from department to department in addition to the expectations placed on GSIs.

1.2. Program Objective

We believe that communities of practice are a powerful resource which departments can leverage to facilitate and sustain GSI adoption of reformed curriculum materials

on a moderate budget. Similar to secondary pedagogical structures that incorporate student-teaching, we recognize that one's first time teaching is a critical time in which one often solidifies methods of instruction for years to come [13]. Thus there are certain common developmental structures GSIs go through during their first few semesters teaching. These may vary with respect to shared resources, but the two universities involved in this study have identified, in terms of praxis, that common struggles include making meaningful mathematical tasks, managing the time required to perform these tasks, anticipating student struggles, and preparing content. We present a process by which all of these common struggles may be addressed at a cost of under \$5000 per course.

We seek to propose a means of focusing the attention of a group of experienced GSIs on adapting an existing well-developed curriculum from one institution so as to reform and localize the curriculum to a completely different institution. Through this adaptation process, we see the seeding of a local community of practice that may sustain itself around the reformed materials. Of particular importance, the reformed curriculum materials, which would include lesson plans, are structured to ensure equitable access to components by all GSIs, and the materials grow and develop over time from suggestions and annotations by GSIs in the community.

The lesson plans themselves mitigate the aforementioned common struggles by providing meaningful mathematical tasks and indicating the time anticipated to implement tasks in the classroom, and the annotations by GSIs help with identifying student struggles. Among other considerations, productive discussion requires a careful selection of tasks which lay the groundwork for a successful class [14]. The remaining common struggle is preparing content. In preparing to teach a class, GSIs traditionally work through a process marked by multiple stages, which we propose an example of as follows:

Traditional GSI Lesson Planning (Teacher-Centered):

1. Identify topics, goals, and objectives for the lesson (often done by reading the title of the section in the book or syllabus)
2. Understand the way in which the curriculum covers the topics and goals (usually by reading the chapter)
3. Think broadly about what the instructor should communicate to emphasize and cover all important concepts
4. Create a lesson plan via a combination of preparing lecture notes, choosing or creating examples (with solutions) to include in a presentation, and/or personalizing how the instructor will get students to engage around the material

Of particular significance is the fact that a GSI engaged in this process may not even consider the local context of the classroom and students until the last step in this process.

The approach described in this paper seeks to transform this traditional, teacher-centered process into a more student-centered design collaboratively established

with fellow GSIs. First, GSIs still start by identifying the topics and goals. However, instead of next looking at the textbook and thinking about areas of emphasis, in this program GSIs look at vetted problem sets and associated polished lesson plans revolving around the problem sets. After reading the lesson plans, GSIs next read suggestions from previous GSIs who actively implemented the lesson plans and decide how to engage their own students with the given lesson plans and problem sets. In this model, the process of preparing is localized to the context of the classroom and students very quickly.

2. RELATED LITERATURE

We provide two lenses, Community of Practice (CoP) and Professional Learning Communities (PLC), in which to discuss the development of this GSI community. We choose to look at GSIs in this project through both lenses because CoPs and PLCs offer complementary perspectives in education when looking at generating and managing knowledge among communities. Blankenship and Ruona [2] compared and contrasted PLC and CoP frameworks in multiple educational settings. They found CoPs emphasize community growth and sustained organizational knowledge, while PLCs require more external leadership and are focused on knowledge generation. In our project, we sought to create a CoP among the GSI community. However, we found the creation of a CoP required a PLC among GSIs first. Thus we look at the larger picture as a CoP to explain the critical pieces of the community, domain, and practice [16] for sustaining cultural change and then discuss how to generate such a CoP by first establishing a PLC framework explicitly among the GSI community, a narrative we describe below in the section Leveraging a Professional Learning Community to Seed a Community of Practice. For now, we give the relevant background information about CoPs and PLCs.

2.1. Communities of Practice

In Reinholz, White, and Andrews' [10] recent article, *Change Theory in STEM Higher Education: A Systematic Review*, a meta-analysis of 97 papers found 40 distinct change theories in STEM higher education. The most prevalent change theory was CoPs. This meta-analysis clarified that CoP predominance is primarily due to its situated and participatory design. Multiple frames for CoPs have emerged in the past two decades [4,11,16] and many expand far beyond education to industry's desire to organize and manage knowledge. Wenger, McDermott, and Snyder [16] founded their work on Lave and Wenger's [7] original work focusing on CoPs from a situated learning perspective that has catalyzed companies to develop formal and informal learning communities.

A CoP is distinct from other networks because it generates networking and knowledge management through three components: Domain, Community, and Practice. The *domain* of a CoP refers to the knowledge that legitimizes and grounds the CoP's identity [16]. The *community* of a CoP centers around interactions and

Table 1. Dimensions of PLCs defined in Hord's framework [6].

PLC dimension	PLC description
Shared and Supportive Leadership	School administration and teachers both lead the school through shared decisions.
Shared Value and Vision	All school leaders and teachers embrace the values and vision.
Collective Learning and its Application	Teachers continuously and collaboratively engage in the inquiry process.
Shared Practice	Colleagues review teachers' professional behavior and practice in a non-evaluative manner.
Supportive Conditions	The physical conditions of the school and the human capital of those involved ensure the success of professional learning communities.

relationships that provide the necessary environment for social learning. Finally, the *practice* of a CoP includes the frameworks, ideas, tools, and methods that a CoP shares. In this paper, we will see how these three components are helpful in understanding precisely how a new community was able to be seeded at a new institutional context, building from the existing domain materials from another institution.

2.2. Professional Learning Communities

PLCs arose in the 1990s as reform-based education methods materialized, expanded through “No Child Left Behind”, and sustained through the generation of teacher leadership, as outlined by Hord [6]. PLCs have often been practiced in school districts for K-12 teachers by providing a 1–2 h meeting time (once a week) during the school day when they can work on collective learning and its application (e.g., practices within their domain for the CoP). Educational PLCs have consistent tension between administrative influence over PLC Time (Top-Down) of how the time should be spent, and the needs and specific challenges of students (Bottom-Up). This is a demonstration of how PLCs often have a stronger top-down leadership than CoPs have among the community. However, it is critical that a shared vision by all stakeholders (school leaders and teachers) allow for this negotiation. This is a distinguishing feature and a necessary structure for implementing curriculum materials with GSIs because an initial leader is needed to organize and catalyze the generation of this community. Hord's [6] framework consists of five dimensions of PLCs, outlined in Table 1.

In this paper, these five dimensions of PLCs provide a framework for us to describe how the GSI community was able to build a CoP as well as describe what can be expected in implementing collaborative curriculum materials among a GSI community. This PLC framework will help us describe the context in a manner that can provide a map for other universities to create and sustain a GSI CoP with limited initial resources.

3. DESCRIPTION OF ENVIRONMENTS

We give some background information about the institutional contexts involved in the study, detailing some of the curriculum development efforts that were occurring at a larger scale prior to and throughout the course of the study.

3.1. University of Nebraska-Lincoln

The curriculum for many first-year math courses is built around problem sets, which began to take shape in the summer of 2014. A faculty position had just been created and filled by a Director of First Year Math Programs, who would support a growing distributed leadership model across many first-year math courses and the development of GSI's pedagogical knowledge and skills. The Director oversaw the work of a number of GSIs to create initial drafts of problem-based materials for precalculus courses. Instructors printed these materials for their own students the first academic year, after which the Director led a team of GSIs in converting the worksheets into a consolidated course packet for each course. Initially, the model involved choosing a few problems from a textbook and asking students to complete those problems during class time while the instructor guided student thinking. However, this structure developed in sophistication over time via ongoing efforts to reflect, iterate, and improve. Ultimately, a robust curriculum centered on refined problem sets evolved and a curriculum was formed which was both independent of a particular textbook and tailored for collaborative learning.

As complexity increased and the need for shared space developed, the Director introduced a department-hosted teaching wiki for all first-year mathematics courses. This wiki is now an important component of the curriculum materials that support novice and developing GSIs' instruction and is used regularly by GSIs. The wiki itself contains information about course materials and lesson plan outlines, and GSIs are encouraged to interact with the wiki in many ways, including using resources to support their instruction and planning, as well as contributing to the wiki of materials, such as by editing existing lesson plans as curriculum changes over semesters or by adding alternate lesson plans or illustrations they have found to be effective.

In its current form, the curriculum at UNL includes features of both "inquiry-based learning" (such as scaffolded problem sets organized so students build ideas together through group work) and "inquiry-oriented instruction" (such as lesson plan structures encouraging instructors to have students present and discuss one another's work), together with supporting materials to help instructors effectively implement the curriculum. The materials at UNL fall within the IBME framework, bringing the aforementioned active learning traditions together [8]. Ultimately, the primary objective of each adaptation process in this multiple case study was to transfer and transform the crucial physical structures (problem sets, collaborative lesson plans) from one institutional context to another; structures which have been shown to support a well-established CoP centered on a robust IBME curriculum at UNL.

3.2. University of South Carolina

For context, we describe some of the support structures for GSIs that existed prior to any community or curriculum reforms as a part of this study. At UofSC, GSIs' first exposure to teaching is as a recitation instructor, facilitating recitations (30

students) for calculus courses by providing support for problems and topics. In their second year of graduate school, GSIs teach Collegiate Algebra, Precalculus, and Business Calculus with the support of two 1-credit hour mathematics pedagogy courses. Prior to 2016, second-year graduate students were extremely limited in providing opportunities to collaborate on teaching methods and lesson design. After 2016, an online cloud was created where GSIs could share content but was often piece-meal in design and emphasized assessment over lesson plans.

At the outset of our study during the summer of 2018, UofSC began a process to standardize and update their precalculus curriculum. A community of GSIs worked together to develop a new precalculus curriculum modeled after the UNL curriculum by adapting materials from UNL. The work was overseen by a local Faculty Facilitator at UofSC, with occasional input from faculty consultants at UNL. The adaptation processes are described in more detail in the Delivery Model section below; the implementation of the adaptation was crucial not only to the transfer of curriculum materials, but also the seeding of new support structures for GSIs.

4. DELIVERY MODEL

In the summer of 2018, researchers at UofSC applied for and received a local grant to reform curriculum materials by adapting UNL's IBME curriculum.¹ This \$10,000 innovative teaching grant over two years (summer 2018-fall 2020) was planned to fund the generation of reformed curriculum materials for UofSC's Collegiate Algebra and Precalculus courses, but as experience was built, the budget was able to be stretched to include Business Calculus. By the completion of the project, the curricula for all three courses were reformed by adapting UNL's IBME curriculum materials, each including a full semester's worth of scaffolded problem sets and associated lesson plans for suggested implementation in the classroom.

For reference, we will break down the funding model more carefully to give a sense of how resources were invested. Half of the grant funding went toward reforming Precalculus (a 4 credit hour course), which required the most oversight by the Faculty Facilitator as they took a hands-on role alongside GSIs to perform the curriculum adaptation. For this first course, just over \$2000 was spent during the summer on salaries for the Faculty Facilitator and GSIs working on the curriculum alignment and adaptation process. The following year, the Faculty Facilitator leveraged the experience of the first adaptation process to take a less direct role in the adaptation of Collegiate Algebra (3 credit hours), spending a total of around \$3000. In fact, only GSIs were paid summer salary to complete the curriculum alignment and adaptation (with some oversight by the Faculty Facilitator). With the remaining \$2000, the Faculty Facilitator was able to budget for a third course to be adapted, Business Calculus (3 credit hours). Each year throughout the project, participating GSIs during the fall semesters were paid around \$500 each to log their time spent in a Journal of Implementation (described below) and to help incentivize their

¹ Yee, S.P. (2018-2020). Active-Learning Lesson Plans for First-Time Graduate Student Instructors. University of South Carolina College of Arts and Sciences Innovative Teaching Associate Grant: Total \$10,000.

engagement with the community (which, as discussed in the Conclusion section, did not actually take up more of a GSI's time than if they had taught independently throughout the semester).

There were two distinct phases associated with each process of curriculum reform: the initial curriculum alignment and adaptation of curriculum materials (which happened primarily during a summer term), and the implementation of reformed curricula (which occurred during each subsequent fall and spring semester). We describe each of these phases in detail below, as well as some data collected from participants while adapting and implementing materials.

4.1. Adapting Curriculum Materials

Each summer for three consecutive summers, one course was the primary focus for curriculum reform via adaptation of UNL materials. Curriculum development teams were led in varying capacities by a Faculty Facilitator and included two GSIs well-versed in the existing curriculum. Using source files for the problem sets and lesson plans provided by UNL, the curriculum development teams focused on making adaptations to the provided base materials necessary to a new local context (see Appendix for examples of an adapted problem set and associated lesson plans). On a large scale, since UofSC was not using the same source textbook as UNL, adjustments needed to be made to the order of material, as well as some omitting or creating of materials that were not in common between the curricula of the two institutions. Within each lesson, problems needed to be adapted to a new local context, and lesson plans needed to be restructured to account for differing pacing of materials.

Each adaptation process started with curriculum alignment, wherein the Faculty Facilitator would discuss with the GSIs working on the adaptation how to align each course's curriculum with UNL's previously established curriculum and IBME materials. The Faculty Facilitator then worked with the GSIs working on the adaptation to generate UofSC-specific reformed curriculum materials from UNL's problem sets and lesson plans.

4.2. Implementation of Reformed Curricula

Each fall semester immediately following the adaptation of curriculum materials and lesson plans, between three to five GSIs (split close to evenly between novice and experienced GSIs) implemented the reformed curriculum in different sections of the associated course. This mixture of both new and experienced GSIs meant that a combination of both fresh ideas and ideas based on practice could be put into the lesson plan comments. An important component of supporting the growing community of GSIs was weekly meetings, typically 1–2 h long. The expectation was established that GSIs would come to a weekly meeting with the next week's problem sets fully completed (by hand), having read the suggested lesson plans and being ready to share suggested changes to the previous weeks' problem sets and

lesson plans that had already been used. The importance of these weekly meetings to provide a PLC structure for the developing community is discussed in the next section, Leveraging a Professional Learning Community to Seed a Community of Practice.

Typically during spring semesters, only one or two sections of each course ran. Meetings among GSIs were much less frequent (if any meetings happened at all), but all GSIs were familiar with the reformed materials and the community of instructors, having already taught the course during the previous fall semester when regular meetings did take place.

For all courses that implemented reformed curricula throughout this study, homework was assigned to students either fully via an online homework system (in which case, no related work was required by GSIs) or half via an online homework system, half via paper (in which case, GSIs had to prepare and grade some written assignments). In addition, each GSI wrote and graded their own individual exams. Their time spent was neither logged nor analyzed on these practices, but this provides some additional context about course structures, and we will comment in the Conclusion about how the community structure influenced the way GSIs prepared assessments.

4.3. Journal of Implementation

Each of the three curriculum adaptation projects (one for each course) had an associated Journal of Implementation, a shared spreadsheet where contributors (GSIs and the Faculty Facilitator at UofSC, and faculty consultants from UNL) logged information about time and focus spent on adapting and reviewing curriculum materials. As previously mentioned, contributors were paid an additional stipend to support their accountability with keeping these logs (and participating in other aspects of the project). A log was created in a Journal of Implementation whenever any contributor worked on the project; each log includes data about who participated, on what day and for how long, and notes about the details of what was worked on. Logs are found in each Journal of Implementation for many types of tasks, from creating or editing problem sets and lesson plans to team meetings with discussions about logistics or pedagogical practices. The descriptions of tasks within each Journal of Implementation serve to enhance and clarify the time that contributors spent on the project. Complementing each Journal of Implementation, additional logs were kept containing information about curriculum alignment. These logs listed out all topics from the UofSC curriculum and included notes about alignment with the UNL curriculum, indicating topics for which lesson plans and materials existed, and what types of modifications would be necessary in order to align to the UofSC curriculum. These additional logs were particularly useful in distinguishing between when existing materials were being adapted as opposed to when new materials were being created.

Data in each Journal of Implementation was analyzed by qualitatively coding the teaching practices using naturalistic inquiry [9]. A constant comparative method

was used to code the entries. A relatively simple coding scheme was established, consisting of five distinct codes. These codes are summarized in Table 2 (including examples of corresponding Journal of Implementation entries) and are described in more detail in the Journal Analysis section below.

4.4. Journal Analysis

Figures 1 and 2 provide a synthesis of the data coded from two of the Journals of Implementation, delineating the breakdown of attention to adaptation and teaching practices by community members throughout the first two adaptation processes. Data analysis for the third Journal of Implementation is ongoing. Here, we discuss Figures 1 and 2 and the analysis of data from the Journals of Implementation, which serves to (1) give an example of what the time and focus demands may be for individuals participating in various aspects of an adaptation and implementation process, and (2) contextualize how that time and focus may change across subsequent adaptation processes (especially for the Faculty Facilitator). We also reference this data in the Conclusion section to establish, using a particular point of comparison, that GSIs were not spending substantially more time preparing to teach by participating in this curriculum adaptation and implementation project.

In Figures 1 and 2, each bar represents one member of the curriculum adaptation or implementation team with the height of a textured region displaying the number of hours that the individual logged in a Journal of Implementation during the specified term on one of the adaptation or teaching practices, coded as outlined above with the codes described in Table 2. A few things to note in these figures: (1) there is no bar for the Faculty Facilitator in either spring semester, indicating that none of their time was needed for that implementation phase, (2) GSI 7 shows up in both figures because they were the only individual who was a part of both of the implementation teams, and (3) GSI 4 and GSI 11 each show up twice, representing GSIs who taught during both a fall and subsequent spring semester using the same curriculum materials. These figures are discussed here, and additional implications are highlighted in the Evidence for Success section below.

Figure 1 shows the Faculty Facilitator worked with two GSIs in the summer of 2018 to adapt curriculum from UNL, focusing on modifying existing materials and creating some new materials. During the fall of 2018, all GSIs within the PLC split their time reviewing materials close to evenly between two practices: “Prepare to Teach” and “Review or Annotate Materials”. Although the “Prepare to Teach” practice was almost always performed individually by GSIs, the “Review or Annotate Materials” category was almost exclusively done during weekly instructor meetings as a PLC network (with a few exceptions when GSIs were annotating lesson plan materials individually). GSIs in the PLC during the fall of 2018 spent between 38 and 48 h on practices relating to reviewing materials. According to all participants’ entries in the Journal of Implementation, it is interesting to note that the amount of time spent on “Review or Annotate” (on average 19.7 h among GSIs) with the PLC in fall of 2018 was very close in value to the time spent on “Prepare to Teach” (on

Table 2. Journal of Implementation codes. Note that the coding of some journal entries for *Create New Materials* and *Modify Source Materials* were informed by the additional logs about curriculum conversion, which indicated the topics for which baseline materials existed in the UNL curriculum. Topics for which baseline materials did not exist had to be created.

Category	Description	Examples from Journals of Implementation
Create New Materials	Develop new content primarily from scratch ** See caption below for additional info about distinguishing this code	• Create problem sets for Ch. 1. • Created Alternate 6.1 Worksheet; Added a problem to help students derive all Pythagorean identities
Modify Source Materials	Edit existing content from original institution to modify activities or align to new curriculum ** See caption below for additional info about distinguishing this code	• 2.1, 2.2 problem sets and objectives + suggested part of the lesson plan • Made changes discussed in the meeting for problem set 2.4/2.5
Review or Annotate Materials	Read over materials to understand them better, annotate lesson plans, or prepare for curriculum adaptation	• Aligning problem set between USC and UNL • A1–A4 Lesson Plans; Updating Online Lesson Plans
Prepare to Teach	Utilize curriculum materials to lesson plan	• Look over worksheet and lesson plans for 2.3 • 6.1 Lesson Prep
Logistics	Discuss logistical plans, such as assigning tasks and sections to individuals during adaptation, agreeing on common formatting of materials, or organizational meetings during implementation	• Organizational work, compiling tex templates for all sections • Listing topics, creating lesson plan templates

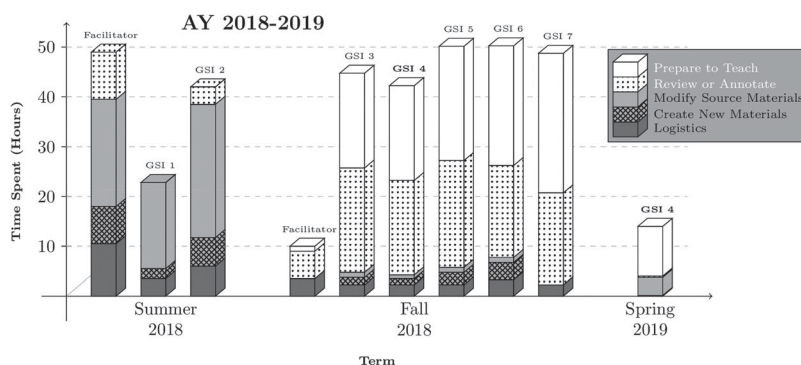


Figure 1. Time and attention to implementation and teaching practices, AY 2018–2019.

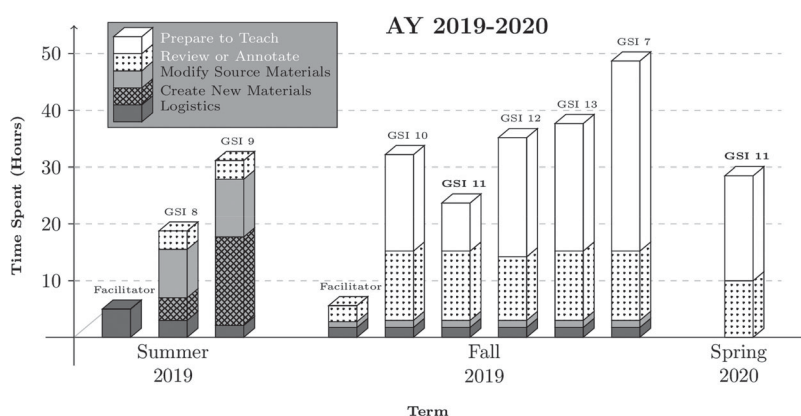


Figure 2. Time and attention to implementation and teaching practices, AY 2019–2020.

average 22.8 h among GSIs), a primarily solitary practice. Moreover, there is a shift in the spring of 2019 to less work with the PLC, which is due to the fact that GSI 4 was the only person instructing a section of the course. On average, GSIs spent a total of 47.4 h in the fall of 2018, and although GSI 4 logged the fewest hours among GSIs (42.3 h) that semester, it is worth noting how many overall fewer hours GSI 4 had to invest in the spring of 2019 (only 14 h total).

The amount of time invested by the Faculty Facilitator varied substantially between the two adaptation processes (AY 2018–2019 and then AY 2019–2020). For the first adaptation process detailed in Figure 1 (including summer 2018, fall 2018, and spring 2019), the Faculty Facilitator was an integral part of the adaptation process, putting in nearly 30 h of work to perform curriculum alignment and subsequently create or modify materials, along with some other tasks, for a total of around 60 h. For the second adaptation process (depicted in Figure 2), the Faculty Facilitator only logged about 10 h of work, having built the experience to be able to reduce the amount of time needed in a direct role in the curriculum adaptation itself and move into oversight of the adaptation work being conducted by two experienced GSIs during the summer term. In many ways, each subsequent adaptation

process got a little “easier”, and we discuss the implications of this relating to the potential impact with limited funding in the Evidence for Success section below.

Figure 2 (AY 2019–2020) describes the time and attention to adaptation and implementation practices of a separate set of GSIs associated with a different course and curriculum than that of Figure 1. Similar to Figure 1, we see that Figure 2 shows in the fall of 2019 that the preparation in the summer (albeit less overall in AY 2019–2020) helped keep “Modify Source Materials” and “Create New Materials” minimal for GSIs implementing the materials in fall 2019. Additionally, during the AY 2019–2020 process, there was slightly more individual time spent on “Prepare to Teach” on average per GSI than time spent to “Review or Annotate”, which was typically done in a PLC context. In practice, this stemmed from the GSIs having a better understanding of autonomous delegation of content so that GSIs were more comfortable assigning homework to each other around polishing lesson plans or adjusting problem sets. The total average time commitment by GSIs in the fall of 2019 was 35.3 h.

In the second iteration (AY 2019–2020), there was an interesting increase in the number of hours logged by GSI 11 (from 23.7 h in fall of 2019 to 33 h in spring of 2020). Two primary factors affected this. First, by looking more closely at the Journal of Implementation, it is clear that the GSI was putting particular effort towards updating and annotating many of the lesson plans, a “Review or Annotate” practice. The second major factor was the COVID-19 pandemic, which forced a dramatic change to an all-remote delivery format of instruction near the middle of the spring 2020 semester. Indeed, GSI 11 logged a majority of their “Prepare to Teach” hours in the Journal of Implementation during the latter half of the semester.

5. LEVERAGING A PROFESSIONAL LEARNING COMMUNITY TO SEED A COMMUNITY OF PRACTICE

Throughout the adaptation and implementation processes at UofSC, we have found success with leveraging the knowledge-generation capacity of PLCs to lay the foundation for a successful CoP. Recall that a CoP is defined by 3 components: the domain, the community, and the practice. In our situation, UNL and UofSC shared a similar *community*, a cohort of GSIs teaching coordinated first-year math courses. UNL had a well-established *domain* (problem sets, lesson plans, and curriculum structure) and *practice* (the shared practices of continuing to refine/contribute to lesson plans and of implementing lesson plans via classroom instruction). Our program’s objective with sharing and adapting curriculum materials from UNL was to utilize PLC structures to focus and support UofSC’s similar *community* of GSIs to reform and implement *domain* materials to fit the *practice* of their own institutional context, thus seeding a new CoP.

The GSI CoP had been previously established at UNL over many years with significant buy-in. The question was about the transferability of the CoP to another higher education institution (UofSC). A CoP annotates and manages knowledge



Figure 3. GSIs working collaboratively in weekly meetings to develop lesson plans and problem sets.

within the domain [16], but UofsC needed to begin such a program, not just sustain it. To seed the context of the CoP, it was necessary to record its development – the features and framework of PLCs (see Table 1) provided the necessary structure to describe its development with the GSI community, as we detail in the following paragraph.

During each fall semester implementing reformed curriculum materials, a cohort of GSIs were hired and expected to meet every week. There was a **shared vision** that they would be expected to share and collaborate teaching materials around student learning. Fundamentally, it was expected that they would **collectively learn** from one another about teaching through regular meetings. The **supportive conditions** were organized by the Faculty Facilitator to include rooms and meetings for 1–2 h once a week with a common screen to look at and access to a central cloud server for collaborative simultaneous work on files during a meeting from multiple computers (Figure 3). **Shared and supportive leadership** stemmed from the Faculty Facilitator organizing the meetings with the expectation of collaboratively looking at (using computers) the lesson plans and problem sets. The Faculty Facilitator led the first two meetings to introduce and model expected norms and structure, but after 3–4 meetings, they had another GSI take a leadership/facilitator role, one who had experience running small group meetings from another peer-mentorship project among GSIs. This leader was expected to not do all the work, but identify when delegating assignments to the other participating GSIs (such as modifying the LaTeX file for the problem sets, or adjusting the timeline suggested for a lesson in the lesson plan) was a better use of their collaborative time. Thus the leadership was truly shared, which promoted autonomy and agency

among the GSIs around the management of teaching knowledge. These weekly meetings, similar to PLCs, had a **shared practice** of coming to the meeting with the next week's problem sets fully completed (by hand), having read the suggested lesson plans and being ready to share suggested changes to the previous weeks' problem sets and lesson plans that had already been used. In addition, novice GSIs working on the project observed one another to gain insight and share feedback around active-learning strategies.

To summarize, although the Faculty Facilitator organized the first few meetings, they focused on setting norms for the meeting structure and then let a GSI take over leading the meetings for the rest of the semester. GSIs came to meetings having looked at upcoming sections, including doing problem sets. During the meetings, GSIs followed a protocol to spend around 10 min delegating out challenges amongst themselves (i.e., go over what happened in the last week and discuss anything that needed to be changed), then talk for around 10 min about how things were going in the present, and finally talk for around 45–60 min about what was coming next (based on their completion of the problem sets prior to the meeting) and decide who would make any changes that were agreed upon. This PLC meeting structure around which GSIs were brought together weekly was the critical foundation for the GSI community.

5.1. The Recipe Unlocked

We will synthesize (and highlight a few figures that help describe) the recipe for leveraging curriculum adaptation and a PLC structure to help seed a new CoP, as well as provide recommendations regarding required resources. In our project, UofSC spent a few thousand dollars each on three separate courses to adapt UNL's IBME curriculum materials (specifically problem sets and lesson plans) to fit their institutional context. Figure 4 gives an overview of the timeline and standard adaptation/implementation practices that occurred with each curriculum reform process.

A Faculty Facilitator worked with or oversaw GSIs during summer terms to complete curriculum alignment, which involved looking closely at UNL's materials and deciding, for each topic in UofSC's curriculum, how much modification would be

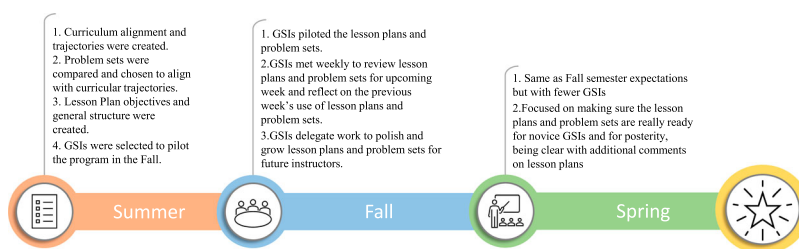


Figure 4. Curriculum reform timeline.

Table 3. Sample PLC implementation.

PLC dimension	Implementation
Shared and Supportive Leadership	Faculty Facilitator organizes the meetings with the expectation of collaboratively looking at lesson plans and problem sets, establishing community norms at the outset, and eventually distributing leadership among the community. GSIs would discuss potential changes to materials they already taught with and delegate individuals to make agreed upon changes to improve the curriculum
Shared Value and Vision	GSIs would be expected to collaborate and share teaching materials around student learning
Collective Learning and its Application	GSIs would collectively learn from one another about teaching through regular meetings, discussing implementation experiences and future plans and strategies
Shared Practice	GSIs would come to weekly meetings with the next week's problem sets fully completed (by hand), having read the suggested lesson plans and ready to discuss and give one another feedback on their own ideas about implementing the upcoming week's lessons. In addition, novice GSIs working on the project observed one another to gain insight and provide feedback around active-learning strategies
Supportive Conditions	Faculty member organizes meetings for 1–2 h once a week with conditions that would support collaboration: • Common central screen to focus on during discussions • Lesson plans and problem sets organized on cloud platform allowing GSIs to simultaneously work on files during editing

required for existing materials (or whether brand new materials needed to be created). The bulk of the adaptation of materials also took place during summer terms, once curriculum alignment was complete. GSIs teaching with new materials participated in structured weekly meetings to have discussions about implementation and instruction, with meetings organized to support a PLC structure. Table 3 summarizes how each dimension of the PLC framework proposed by Hord [6] was tended to in these meetings. Through this process, a CoP is seeded: a shared *domain* of curriculum materials is created, which a *community* of GSIs (with the common *practice* of instructing with the materials) come together in supportive conditions to discuss and improve upon. The shared curriculum materials and annotated lesson plans form a basis around which the community can sustain itself, even as GSIs come and go to teach other courses.

Certain resources and conditions at UofSC and UNL facilitated the curriculum reform process and seeding of a CoP described here, but another institution seeking to do the same may have different (or fewer) resources available. We give some recommendations here for other institutional contexts. An important component of our process was the existing IBME curriculum materials that UNL shared with UofSC for adaptation - we would encourage other institutions to explore open education resource materials that may be similar to their existing curriculum, or to reach out to the authors of this report to discuss the prospect of sharing resources. Another important component was the local funding at UofSC, but we argue here that the process can be completed for a few thousand dollars per course, so we would encourage others to make a case for the potential impact and seek their own local, departmental, or college funding. We do not believe that graduate students are a necessary component of the process - a CoP could be seeded among any group of instructors willing to work on adaptation and collaborate on and discuss teaching materials. And finally, other institutions may wish to carry out aspects

of our implementation differently, but one crucial aspect is to ensure that all PLC dimensions are addressed among those teaching with new materials.

6. EVIDENCE FOR SUCCESS

The adaptation processes carried out at UofSC provide a proof-of-concept for building reformed and sustainable curriculum materials with limited resources, and the subsequent implementation of reformed materials using a PLC model illustrates the potential for supporting GSIs by reallocating time away from individual preparation toward valuable community-based discussions among practitioners. In this section, we lay out some of the evidence of this success, followed by a short vignette about an experienced GSI which will help contextualize our final discussion below.

The Recipe Unlocked section above outlines how Hord's [6] PLC framework may be leveraged (with flexibility, depending on context) as part of a process of efficiently adapting and implementing reformed curriculum materials. Indeed, with local grant funding, UofSC successfully reformed curricula for three distinct courses (and the impact-to-cost ratio increased with each subsequent adaptation process). Not only do the created materials support many GSIs every semester, but very importantly, mechanisms are embedded to help iterate upon and sustain the materials for many semesters to come. We see evidence of this with UNL's implementation; these same structures - the rich problem sets, the open-source shared lesson plans and teaching objectives - have played an integral role in the development and sustainability of UNL's curriculum for many years.

Figure 1 will play a role in illustrating an important component of the impact and success of this recipe, namely the reallocation of time and focus by GSIs away from creating materials from scratch toward reviewing and discussing reformed materials as a community. We highlight the value of this reallocation of time and focus in the Conclusion below, but first, it will be helpful to establish a baseline of the amount of time and focus that an experienced GSI might have spent on preparing to implement the same curriculum without integration in the PLC via weekly meetings and collaboration. We establish this baseline with a brief aside about Juan, a fourth-year mathematics doctoral student with significant teaching experience, as well as advanced education on teaching and pedagogy.

During the fall of 2019, those GSIs who chose not to use the reformed curriculum materials were offered a small stipend to record the time it took them to prepare to teach (along with other teaching-related duties). Juan volunteered to be part of the study, keeping a journal while serving as a GSI for a math course whose curriculum had been reformed the previous academic year as a part of this study. Juan did incorporate group activities and interactive lessons, but he neither used the reformed curriculum materials nor met weekly with a PLC network of instructors. Rather, he worked independently on his own lesson planning all semester. Juan kept track of the number of hours he spent utilizing curriculum materials at his disposal in order to prepare "Lecture Notes", among other teaching practices. Juan, an experienced GSI, logged 41.5 h working on lecture notes in preparation to teach in the classroom.

This data from Juan, a highly experienced instructor who worked solo to create their own lesson plans and materials, gives one point of comparison for GSIs participating in PLC meetings and implementing and contributing to reformed materials (which we elaborate on in the Conclusion below).

6.1. Conclusion

In The Recipe Unlocked section above, we propose a process involving major change to seed a CoP using a PLC structure. This process addresses three of the primary barriers (inadequate resources, time constraints, and absence of supportive culture) identified by Shadle et al. The inadequate resources barrier is mitigated by identifying existing curriculum materials (e.g., the IBME curricula from UNL) for which curriculum alignment and adaptation may be performed to fit a new institutional context. This gives community members a common set of materials to use in their instruction, have discussions about, and improve upon as a PLC. We discuss as follows how the preparation for teaching and PLC meeting structure relate to GSI's time, and we provide some evidence that the process can help build and sustain a supportive culture around instruction with these reformed IBME materials.

The breakdown of the allocation of time and focus by the GSIs implementing reformed materials as part of a PLC (depicted in Figure 1) includes two practices that involve reviewing curriculum materials, either in lesson planning ("Prepare to Teach") or in comprehending, discussing, or annotating the materials ("Review or Annotate Materials"). The reallocation of time by GSIs away from individual lesson planning toward PLC interactions demonstrates support for the newly established CoP centered on instructing with these materials. Indeed, the PLC framework encourages the existing *community* of GSIs to engage in the shared *practice* of making sustainable contributions toward the *domain* materials (especially by refining the problem sets and annotating lesson plans) based on individual GSIs' ideas and implementation experiences, as well as discussions among the community.

Using Juan as a point of reference (41.5 h preparing lecture notes), GSIs on average did not spend considerably more time interacting with curriculum materials, and importantly, spent a substantial portion of time interacting with curriculum materials as a community rather than on their own throughout the semester. As discussed in Figure 1, the mixture of novice and experienced GSIs in the PLC during the fall of 2018 (who taught the same course as Juan taught in fall of 2019) spent between 38 and 48 h on practices relating to reviewing materials. Having just this single point of reference is limiting, but Juan was the only GSIs in the fall of 2019 who wished to create their own materials instead of using the adapted materials.

Providing GSIs with a starting point in the form of IBME lesson plans gives them something concrete around which to build conversations in PLC meetings. This empowers the voice of novice GSIs in particular, for whom it may be easier to discuss and critique a complete plan laid out before them than to build a lesson plan from scratch to discuss with a group. Therefore, the community is able to strive for

equitable access among novice and experienced GSIs alike to not only curriculum materials but also the practice of discussing and contributing to the continual development of materials. Simultaneously, the lesson plans provide a concrete starting point without forcing a single particular teaching style; in fact, diversity of teaching practices is encouraged by GSIs contributing annotations to lesson plans about their experiences with implementing and modifying the lessons.

Being a part of this community had many impacts on GSIs. While teaching and participating in a PLC, each GSI had to write their own exams throughout the semester. The PLC meetings focused exclusively on discussing curriculum materials and teaching. Nonetheless, some groups of GSIs found themselves collaborating with one another to prepare assessments with others in the community teaching the same course, evidence that the community structure was expanding beyond the PLC meetings themselves.

Another important impact can be seen in a shift toward active problem-based teaching practices by all GSIs who participated in the project. A number of participants went on to continue teaching courses with reformed materials, and every one of them continued using the problem sets and lesson plans. Further, those GSIs who participated and were subsequently assigned new preps for courses without problem sets made their own new problem sets. After having built a foundation of practice among the community for building and instructing with problem sets, it was less work for them to implement this curriculum structure in another course, even without regular PLC meetings. This suggests that “curriculum leaders” may form from the community who could help facilitate a more systemic spread of the curriculum structure and materials that GSIs in the community worked with.

A third impact of the GSI community manifested during the COVID-19 pandemic. Many familiar course structures were no longer an option, and instructors were left searching for functional alternatives. The community showed great resilience – GSIs were open to coming together and having productive discussions around curriculum problem-solving, an important professional skill developed during PLC meetings.

Looking back many semesters later (and after the seed funding has expired), the courses which underwent a curriculum reform process continue to cycle through cohorts of GSIs with varying levels of experience who not only implement the curricula but continue to polish and contribute to the lesson plans and problems sets to support ever-evolving curricula. These contributions continue to accumulate over time to form a diverse wellspring of knowledge and perspectives from many instructors that current and future GSIs might use to inform their lesson planning, whatever their teaching style may be.

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REFERENCES

- [1] Belnap, J. K., and K. N. Allred. 2009. Mathematics teaching assistants: their instructional involvement and preparation opportunities. In Laura L. B. Border, Natasha Speer and Teri J. Murphy (Eds.), *Studies in Graduate and Professional Student Development: Research on Graduate Students as Teachers of Undergraduate Mathematics*. 12, pp. 11–38. Stillwater, OK: New Forums Press.
- [2] Blankenship, S. S., and W. E. Ruona. 2007. *Professional Learning Communities and Communities of Practice: A Comparison of Models, Literature Review*, available at <https://eric.ed.gov/?id=ED504776>.
- [3] Bressoud, D. M., V. Mesa, and C. L. Rasmussen. 2015. *Insights and Recommendations from the MAA National Study of College Calculus*. New Denver, BC V0G 1S0, Canada: MAA Press.
- [4] Brown, J. S., and P. Duguid. 1991. Organizational learning and communities-of-practice: toward a unified view of working, learning, and innovation. *Organization Science*. 2(1): 40–57.
- [5] Freeman, S., S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth. 2014. Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*. 111(23): 8410–8415.
- [6] Hord, S. M. 2004. Professional learning communities: An overview. In Shirley M. Hord and Joseph F. Murphy (Eds.), *Learning Together, Leading Together: Changing Schools Through Professional Learning Communities*, pp. 5–14. New York, NY: Teachers College Press.
- [7] Lave, J., and E. Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation*. Cambridge, UK: Cambridge university press.
- [8] Laursen, S. L., and C. Rasmussen. 2019. I on the prize: inquiry approaches in undergraduate mathematics. *International Journal of Research in Undergraduate Mathematics Education*. 5(1): 129–146.
- [9] Lincoln, Y. S., and E. G. Guba. 1985. *Naturalistic Inquiry*. Thousand Oaks, CA: Sage.
- [10] Reinholz, D. L., I. White, and T. Andrews. 2021. Change theory in STEM higher education: a systematic review. *International Journal of STEM Education*. 8(1): 1–22.
- [11] Saint-Onge, H., and D. Wallace. 2003. *Leveraging Communities of Practice for Strategic Advantage*. Boston, MA: Butterworth-Heinemann.
- [12] Shadle, S. E., A. Marker, and B. Earl. 2017. Faculty drivers and barriers: laying the groundwork for undergraduate STEM education reform in academic departments. *International Journal of STEM Education*. 4(1): 1–13.
- [13] Speer, N. M., J. P. Smith III, and A. Horvath. 2010. Collegiate mathematics teaching: An unexamined practice. *The Journal of Mathematical Behavior*. 29(2): 99–114.
- [14] Stein, M. K., and M. Smith. 2011. *5 Practices for Orchestrating Productive Mathematics Discussions*. Reston, VA: National Council of Teachers of Mathematics.

- [15] Uhing, K., D. Webb, N. Wakefield, A. Donsig, and C. Rasmussen. 2021. Professional development. In Wendy M. Smith, Matthew Voigt, April Ström, David C. Webb, and W. Gary Martin, (Eds.), *Transformational Change Efforts: Student Engagement in Mathematics Through an Institutional Network for Active Learning*. W. Gary Martin, American Mathematical Society, Providence, RI. 138, p. 243. Providence, RI: American Mathematical Society.
- [16] Wenger, E., R. A. McDermott, and W. Snyder. 2002. *Cultivating Communities of Practice: A Guide to Managing Knowledge*. Boston, MA: Harvard Business Publishing.

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