AN EXAMINATION OF FACTORS THAT SUPPORT SUSTAINABLE CULTURAL AND CURRICULAR CHANGE IN STEM TEACHING AND LEARNING

Erica Slate Young
Appalachian State University
slateer@appstate.edu

Peaches Hash
Appalachian State University
hashpe@appstate.edu

Sarah Schott
Duke University
schott@math.duke.edu

Jack Bookman
Duke University
bookman@math.duke.edu

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ABSTRACT
Using a mixed-methods design, this body of work from the SUMMIT-P consortium explores possible effective conditions for the sustainable reform of STEM teaching and learning at the collegiate level. A model of catalysts for successful and sustainable change is proposed, based on five years of data collection and observations. These catalysts include institutional support, intrinsic and extrinsic motivation of faculty involved, measures of student success, institution size, prior faculty experience, faculty buy-in, and institutional culture. The discussion ends with a delve into the potential broader impacts of this work. For example, this model may help institutions better understand how to implement curricular change more effectively.

KEYWORDS
evaluation, STEM teaching, sustainable change

Since 2016, the members of A National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnership (SUMMIT-P) have been working to establish interdisciplinary Faculty Learning Communities (FLCs) in order to revise and improve the teaching of mathematics in lower division college classes. (For additional background information and details regarding the SUMMIT-P consortium, we refer the reader to Ganter and Haver (2020).) The changes sought as part of the SUMMIT-P project are not merely revisions to the content that is taught, but also to how the content is taught.

The term *curriculum* is interpreted in many different ways. Some consider the term curriculum to refer strictly to what is taught, while others consider it to be a combination of what is taught and how it is taught; we take the latter view. We therefore see curricular change as change within course materials as well as change in teaching practices. Curricular materials are more tangible than faculty professional development, and so are often the focus of many reform efforts. The development of curriculum materials alone may not have a lasting impact. It is difficult to ensure fidelity to materials without the corresponding faculty professional development. The materials themselves may remain in courses, but may not be implemented with an adequate focus on active learning. More than just seeking to develop new curricular approaches, the members of the SUMMIT-P consortium are working to change the faculty teaching practices to promote more active learning strategies. In some cases, this also requires changing the *culture* of their departments or institutions. Here we use the term *culture* as defined by Reinholz and Apkarian (2018), "[c]ulture is a historical and evolving set of structures and symbols and the resulting power relationships between people," (p.3). The *structures* referred to here are "the roles, routines, and practices of a department," (Reinholz & Apkarian, 2018, p. 5); these structures are contingent on the *symbols*, "which are the norms, values, and ways of thinking in a department," (Reinholz & Apkarian, 2018, p. 5). These definitions of curriculum and culture have guided the work we present below.

Over the past five years, we, the research team, collected responses from participants to periodic prompts, participated in site visits, and conducted interviews and focus groups. Using a mixed-methods design, our analysis of data collected as part of the research and evaluation of the SUMMIT-P consortium explores possible effective conditions for the sustainable reform of STEM teaching and learning at the collegiate level. From these data collections and observations, we developed a model of catalysts for successful and sustainable change that we will discuss in this paper.

Research on Change Strategies

Henderson et al. (2011) conducted an extensive literature review of journal articles published between 1995 and 2008 that discussed promoting change in instructional practices of undergraduate science, technology, engineering, and mathematics (STEM) courses. They categorized their findings into four broad categories of change strategies. The first category is "Individual/Prescribed," which focuses on disseminating curriculum and pedagogy through "communicating the change agent's vision of good teaching to individual instructors" (p. 2). The change agent promotes change by using their specialized knowledge to show others new ways to create curricula or teach. Henderson et al.'s (2011) second category is "Individual/Emergent," a category that focuses on developing reflective teachers by encouraging teachers "to use their own knowledge/experience/skill to improve their instructional practices" (p. 10). The change agent encourages teachers and supports reflective practices as they identify areas they wish to

improve. The third category, "Environments/Prescribed," focuses on enacting policy. This type of intervention emphasizes "developing appropriate environments (e.g., rules, reward systems, reporting requirements, investments in support structures) to facilitate instructors engaging in specific or desired activities" (p. 11). The change agent develops new environmental elements that promote new behaviors or attitudes, leading to changes in instruction. Under this category, change agents have a specific vision that educators work towards developing. Henderson et al.'s final category is "Environments/Emergent," which focuses on a shared vision between stakeholders. The change agent works towards empowering individuals "to come together and work toward collectively envisioned change (p. 12).

In their review of articles, Henderson et al. (2011) found that there were similar numbers of articles that fit into the Curriculum & Pedagogy, Reflective Teachers, and Policy categories, but fewer that fit into the Shared Vision category; however, the scholars also noticed divides in categories based on the types of research being conducted. Henderson et al. (2011) note that STEM education researchers write about disseminating curriculum and pedagogy when they refer to change, while faculty development researchers focus on change that develops reflective teachers. Higher education researchers, in contrast, largely focus on change that results in enacting policy. Henderson et al. (2011) also highlights that only 21% of the articles they reviewed presented strong evidence of success or failure of the change strategy; however, the scholars were able to conclude from their literature analysis that effective change strategies align or seek to change beliefs, include long-term interventions, and design strategies for complex systems.

Effective change strategies may include specialized models designed for professional growth. In their research with K-12 teachers, Clarke and Hollingsworth (2002) state that change is often viewed as something "done to teachers" (p. 948) where teachers have little agency in the process. The effect of this lack of agency is that less change occurs because teachers are not invested. Clarke and Hollingsworth (2002) express that professional development designed for change must move away from the deficit-training-mastery model to one where teachers are active participants in learning and reflection. They propose the Interconnected Model as a solution to teachers' lack of agency. The Interconnected Model involves change occurring through mediating processes of reflection and enactment in four domains that encompass teachers' worlds: "the personal domain (teacher knowledge, beliefs, and attitudes), the domain of practice (professional experimentation), the domain of consequence (salient outcomes), and the external domain (sources of information, stimulus or support)" (p. 950). These domains are categorized into two types, the external and the personal. The Interconnected Model encompasses the complexity of professional growth by identifying multiple growth pathways between domains. It is a nonlinear model that "recognizes professional growth as an inevitable and continuing process of learning" (p. 950).

Gess-Newsome et al. (2003) also promote a change model that involves viewing teachers as dynamic individuals. The Teacher-Centered Systemic Reform model (TCSR) is a framework to understand how teachers' beliefs are shaped and may influence their professional behaviors. The TCSR involves "teaching context, teacher characteristics, teacher thinking, and their interactions as influential factors in attempts to implement classroom reform" (p. 731). Gess-Newsome et al. (2003) propose that interventions, teacher dissatisfaction, and changes in personal practical theories are the most impactful influences on the enactment of reform. When teachers experience pedagogical and contextual dissatisfaction, there is an opening for fundamental change.

Change strategies facilitate growth in groups of educators as well as individuals. Stein and Short (2001) note the benefits of working with faculty in collaborative groups, explaining that "[g]roup work can be superior to individual work because group products may exceed both the potential of the most talented participant and the potential of the separate efforts of group members working individually" (p. 419); however, the scholars also recognize that personal barriers such as lack of interpersonal skills and style, as well as social and psychological forces, can negatively impact group collaboration. To make group collaboration a positive, beneficial experience, Stein and Short (2001) recommend that educational leaders define the type of collaboration teachers will participate in beforehand and consider strategic decisions such as pacing of interactions, acknowledging differences within the group, and using innovation to increase chances of the collaboration's success. Beach and Cox (2009) sought to develop the teaching abilities of junior faculty within a consortium of institutions through faculty learning communities. Beach and Cox (2009) define FLCs as "safe, supportive communities in which faculty and professional staff can investigate and take risks in implementing new approaches to teaching and by increasing the collaboration and coherence of learning across disciplines," (p. 7). Each FLC was made up of cross-disciplinary faculty communities of 8-12 people that focused on an active, collaborative curriculum designed to enhance undergraduate learning. Beach and Cox (2009) found that the faculty who participated in the FLCs reported "at least moderate changes in student learning 1-3 years after their participation" (p. 24). The faculty were trying different approaches to teaching and noted impacts on student learning that they credited to their participation.

Bolman and Deal (2008) recognize that leaders often contribute too few new or innovative ideas when facing organizational problems and challenges, instead relying on habitual responses. These habitual responses lead to a limited cognitive perspective, where leaders can only see one way to handle a particular problem. The result is that leaders are less capable of responding to complex problems. Bolman and Deal's (2008) solution is to teach leaders to reframe so they can approach problems in a new light. Educational leaders seek to help teachers develop through change theories that will lead to programmatic change.

The Framework for our Exploratory Research

We would like to make clear that the work we present here is the result of exploratory research used for generating hypotheses. The model we propose is based on our research conducted using a grounded theory approach (Glaser & Strauss, 1967), utilizing a small sample size and largely qualitative methods. Our subjects were the PIs and co-PIs of the SUMMIT-P consortium, but we also observed other elements within the scope of the project. We participated in site visits to each of the institutions, where we were able to observe classes taught by SUMMIT-P faculty. During site visits, we had the opportunity to conduct focus groups with students in the SUMMIT-P classes and have informal conversations with other faculty and administrators at the institution. We were also able to use our time during the annual SUMMIT-P meetings to conduct focus group sessions with the participants in the project. These elements all served as supplementary data giving us insights into some of the unique cultural aspects unique to the individual institutions.

Our primary source of data from the participants came in the form of the Evaluation Portfolio (Slate Young et al., 2020). Several times per year, we would ask the SUMMIT-P participants to respond to a reflective discussion prompt. Each prompt was tailored to give us

insights into individual faculty members' perspectives on their efforts related to the SUMMIT-P project at their institution. For example, we posed this prompt near the midpoint of the project:

> *Think back to your early experiences teaching compared to now. Describe a way in which your teaching has changed. What were your reasons for that change? (Tell us the story about how that change happened.)*

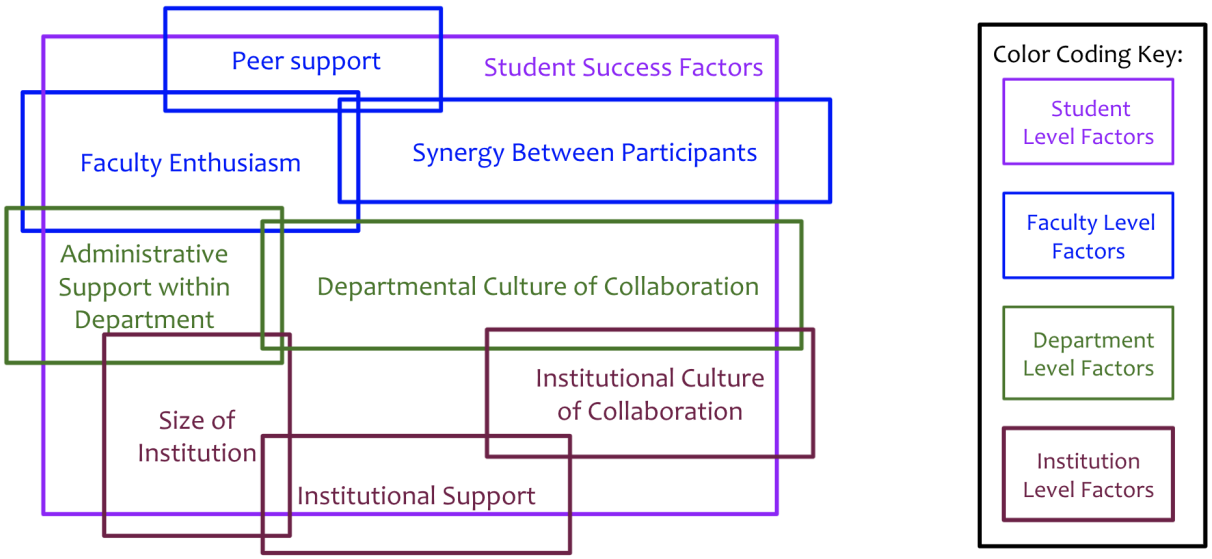
We examined the responses to each prompt looking for trends or commonalities in the responses. We were able to then use observational data from site visits and the annual SUMMIT-P meetings to triangulate our results.

An Emergent Model of Sustainability Factors for Interdisciplinary Collaborations

From our examination of the qualitative data gathered in the site visits, portfolio responses, focus groups, and other evaluation activities discussed above, we concluded that some institutions were more successful in implementing changes and were more likely to sustain those changes. We grouped the nine institutions into three tiers – successful, moderately successful, and struggling – and then listed which observations and factors contributed to this classification of their level of success. This evaluation led us to propose a model of interlacing factors described below in Figure 1. We would like to emphasize that each institution in the consortium had its own strengths and challenges and therefore the model is very much context dependent. Our model described below illustrates some of the primary factors we observed that contribute to the success of a project, however, we would be remiss if we did not acknowledge the caveat that we observed one element is constant across all programs: there needs to be a powerful catalyst to begin the change process and most often this is in the form of one dedicated, devoted leader. The efforts of this leader will not be sufficient to sustain the change; sustainable change requires more than the efforts of a single faculty member; how much more is required, depends on the institution.

Figure 1

An Emergent Model of Factors Contributing to Sustainability of Interdisciplinary Collaborations



Description of Sustainability Diagrams

The model in Figure 1 describes four primary factors that we theorize have an impact on the sustainability of a project within an institution. In this diagram, we attempt to capture the idea that many of these factors interrelate with one another, but these interactions are complex and difficult to capture. For instance, in the diagram above, we show that student success factors overlap with all other factors because, often, these student success factors impact, or are impacted by, the level of support from other faculty, from the department, and from the institution. This is given as a hypothetical example of the relationships of the items in the diagram (e.g., overlap). Each institution would have its own unique model, with the various factors overlapping in different ways. Below, we provide our working definitions of each of the factors included in our model and offer vignettes solicited from participants at various SUMMIT-P institutions to further illustrate the definitions.

Student-Level Success Factors

This factor encompasses several aspects of how the project impacts students. The focus of the SUMMIT-P project is primarily on faculty development; however, a positive impact on students is the ultimate goal and certainly plays a role in the potential for sustainability of the project. Student Success factors include, but are not limited to, overall student performance in SUMMIT-P related courses (i.e., grades, D-F-W rates, etc.), student performance on assessments, student performance in follow-on courses, and attitudinal aspects such as students' perceived relevance of the content, student attitudes toward the content, and student participation and engagement in class.

Vignette – Importance of Student Success Factors

At Lee University, as part of the requirements of our program, all elementary education majors must pass a "Mathematics Manipulatives Assessment." In this assessment, students are asked to demonstrate various mathematical principles using commonly available manipulatives used in elementary classrooms (Cuisenaire rods, unifix cubes, pattern blocks, etc.). Historically, the first-time pass rates for this assessment were relatively low and math anxiety was very high. This was an issue discussed by the mathematics and education faculty at the start of the SUMMIT-P project at Lee University. In response to this issue, the mathematics faculty began incorporating manipulatives into mathematics courses for elementary education majors. Education faculty also emphasized the use of manipulatives in an elementary teaching methods course. As a result, the first-time pass rates on the Mathematics Manipulatives Assessment began to improve. Because of the evidence gathered of the direct positive impact on students, there is a greater level of buy-in from the mathematics faculty teaching the course(s) for the prospective elementary teachers. This change will likely be sustained past the life of the SUMMIT-P project.

Faculty Level Factors

Peer Support. If a project is viewed favorably by peers, faculty are more likely to expend effort toward it. With the varying expectations of teaching, research, and service placed on faculty members, one is rewarded for time spent on activities that are deemed worthwhile. This is especially true for pre-tenured and non-tenure track faculty. Peer support for the project also includes faculty buy-in and the willingness of peers to adopt pedagogical changes associated with the project.

Enduring Faculty Enthusiasm. There must be a critical mass of faculty with the experience, mental energy, and time commitment available to devote to the project. A project of this magnitude cannot be sustained by the efforts of a single faculty member, regardless of how committed that faculty member is to the work. This is more than a curriculum development project – it is a faculty development project. The faculty member's level of experience with curriculum projects is another important element. Participating faculty must believe in the value of the project and feel that they have the ability to make the changes required for the project. In some of our observations, the presence of this factor was a primary reason for success. Conversely, in at least one case, the absence of this factor was a reason for the lack of progress.

Synergy Between Participants. This particular project involved the collaboration of faculty across disciplines. The most successful institutions worked to establish a steady line of communication between participating departments. In particular, the development of an FLC proved to be particularly successful in making participants feel accountable toward one another, as well as toward the project. Also, if the faculty working together have certain collegial qualities that promote harmony within the team, the project is more likely to be sustainable.

Vignette – Importance of Faculty Level Factors

At Augsburg University, the faculty involved in the SUMMIT-P project had all had extensive teaching experience, ranging from 14-35 years each. Several of us have been involved with curriculum reform projects. Academic departments are small and the institution is based on a teacher-scholar model, that is, the teaching is a high priority for tenure and other reviews and scholarship focuses on teaching and student learning. Members of the team have worked together for 14 years, two for 33. The university values and rewards interdisciplinary work of many kinds. After years of working together, the mutual respect we have for each other has helped to promote the synergy of the group. We intend to continue using the products we developed, incrementally improving, evolving, and replacing them over time. We will continue to collaborate and are discussing possible collaboration on the mathematics in the General Chemistry course which has been identified by the university as a student success roadblock.

Department Level Factors

Administrative Support (within department). In order for a project such as SUMMIT-P to be sustained, there must also be administrative support factors at the department level. These factors include the ability for course changes to be codified into the course description and/or syllabus for a particular course, and accommodations made in course scheduling to allow for consistent, and predictable scheduling of faculty, including non-tenure track faculty, teaching the impacted courses.

Departmental Culture of Collaboration. In departments where collaboration among colleagues was already an established practice, the work done as part of SUMMIT-P was a more organic process. However, in departments where collaborative work was not the norm, extra efforts needed to be made in order to promote collaboration. The peer support element discussed above is strongly tied to this factor. In addition to the culture of collaboration among faculty within a department, there should be a perceived value of interdisciplinary collaboration with other departments, and these collaborations should be valued by the department when it comes to performance reviews.

Vignette – Importance of Department Level Factors

At one SUMMIT-P institution, the project originally planned on focusing on integrating biology concepts into the calculus curriculum. The PI was expected to be one of the calculus instructors and therefore had the authority to pilot the initial changes within the sections they taught. After the initial planning phase, before the curricular changes were implemented, the PI was informed that they would not be teaching calculus. Therefore, the work for SUMMIT-P needed to be re-framed for a new mathematics context, causing a delay in the implementation. Although there was a loss of momentum, the team was able to revise their plan, including both the content and project timeline. This is an example of how competing administrative pressures in a department serving large numbers of students can create difficulties.

Institution Level Factors

Size of Institution. Most large universities are siloed (within schools or departments). This can potentially impact the ability to collaborate. Conversely, in some cases, smaller institutions have more opportunities for cross-discipline collaboration.

Institutional Support. This factor covers a wide variety of elements. A project is more likely to be successful and sustainable if the institutional priorities concerning undergraduate education are conducive to interdisciplinary collaboration. Different institutions prioritize research, graduate education, and undergraduate education in different ways. If an institution has a history of innovative support for faculty, such as an active Teaching and Learning Center, support and/or incentives for collaboration (e.g., FLCs), and support or incentives for curriculum innovation, then that works in favor of projects like SUMMIT-P. For these projects to be successful and sustainable, educational innovation should be recognized and supported in a meaningful way at the institutional level (e.g., financially or credit towards promotion).

Institutional Culture of Collaboration. Much like the "department culture of collaboration" factor (see Figure 1), an established culture of collaboration in an institution contributes to the success and sustainability of a project like SUMMIT-P. Across different departments in the institution, the following questions should be addressed to gauge and improve the institutional culture of collaboration:

- Do faculty regularly collaborate to share ideas about teaching or research?
- In addition to the culture of collaboration within an institution, is there a perceived value of interdisciplinary collaboration across departments?
- Are these collaborations valued by the institution when it comes to decisions about reappointment, promotion, tenure, and post-tenure reviews?
- Logistically speaking, is there time and space allocated for faculty collaboration?

Vignette – Importance of Institution Level Factors

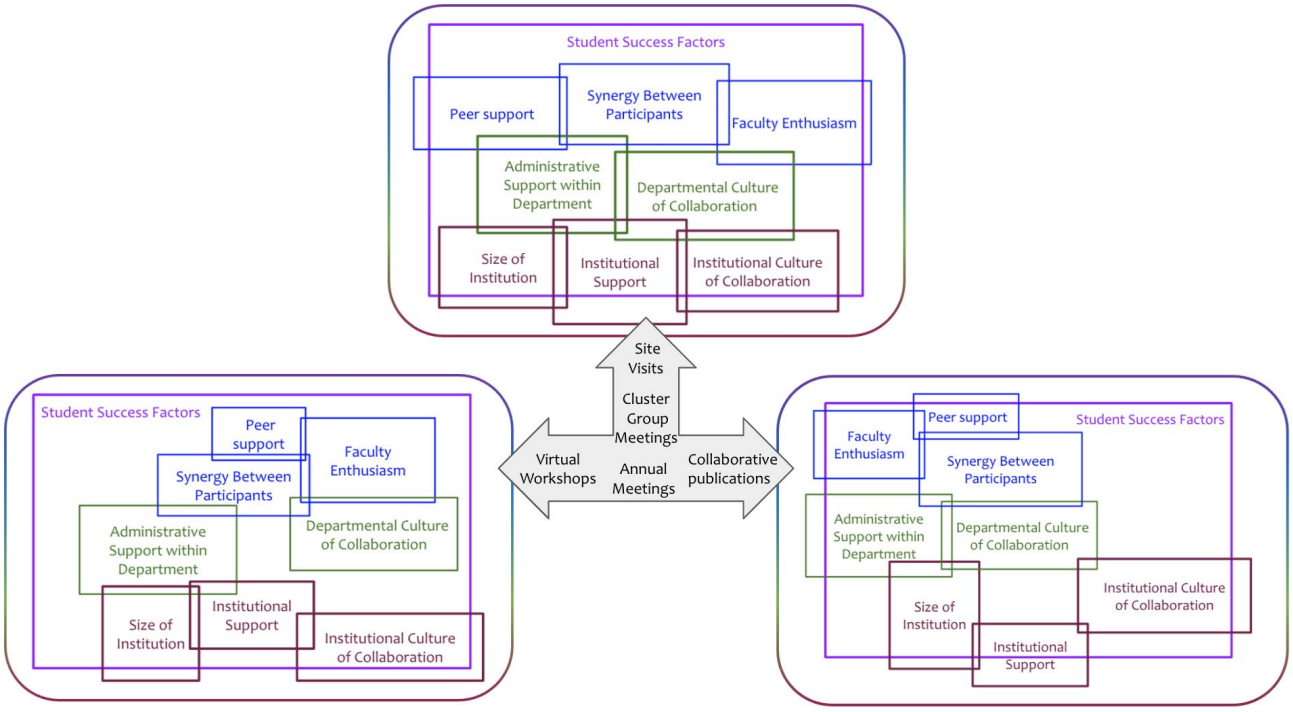
For many years, FLCs have been part of the institutional culture at Ferris State University. There is a dedicated space in the Ferris Library for Information, Technology, and Education set aside for FLCs to meet. The university offers professional development incentive funds for participants who successfully complete an FLC. Therefore, our participation in the SUMMIT-P consortium fit naturally into that structure. Also, our institution has prioritized quantitative literacy across the curriculum in the general education program, therefore the collaborative work done for our SUMMIT-P project aligns well with the institutional goals. These factors will help to promote the sustainability of our project.

Multi-institution Factors

In addition to the work being done at individual institutions, the SUMMIT-P consortium structure provided a catalyst for work to be done across multiple institutions. The consortium structure also may have helped keep the momentum going at the institutions because of the accountability that comes with being part of a larger project. In addition to the FLCs that were formed, the site visits, Principal Investigator meetings, and the annual consortium meetings helped create a sense of community of practice which in turn fostered the collaborations. The diagram in Figure 2 illustrates the factors outside of a single institution that impacted the collaborative work across institutions within the SUMMIT-P consortium. Each institution in the diagram is represented with a slightly different version of our model to denote that each institution has its own unique internal factors. For simplicity, we limited the diagram to three institutions rather than including all 12. The arrows represent the activities within the SUMMIT-P project that were the most impactful in promoting multi-institutional collaborations: site visits, cluster group meetings, virtual workshops, collaborative publications, and the annual SUMMIT-P meeting.

Figure 2

Multi-Institutional Factors Contributing to Sustainability of Interdisciplinary Collaborations



Vignette – Importance of Multi-Institution Factors

Norfolk State University (NSU) has been a SUMMIT-P institution since the project was first funded in 2016. Two years into the project, after the departure of co-PIs from the mathematics department and its partner discipline, engineering, NSU found its project in a state of disarray. The leadership team at NSU was overwhelmed with no clear direction to follow. A new leadership team was formed to rejuvenate the project, but there was one nagging question that bothered the new team members. "How do we jump start the project and what direction

should we take to make up for the lost time?" This question was the main topic of discussion at a two-day site visit hosted by NSU in the Spring of 2019. The visiting team consisted of two SUMMIT-P faculty from Virginia Commonwealth University (VCU) and two members from the project management team. In order to assist NSU's leadership team with their dilemmas, the site visit team recommended that, as part of their SUMMIT-P project, NSU offer a number of summer opportunities to members of mathematics and engineering faculty to collaborate on creating interdisciplinary examples. These summer collaborations strengthened the relationship between faculty in mathematics and engineering and ultimately enabled NSU to revive its project, develop effective materials, and contribute to the overall SUMMIT-P project.

Discussion and Conclusion

As stated earlier, this emergent model is based on our exploratory research. Future work needs to be conducted to verify our model and to add a deeper understanding of how the pieces work together. We have a small sample size and therefore our generalizability is limited. However, we see this framework as a starting point for understanding the various factors that contribute to the sustainability of innovations in educational settings. As it stands, our model could be used by departments or programs as part of a self-assessment instrument. It would be a useful reflective exercise to examine how the factors at each level interact and overlap within a particular context. For instance, in our model, we hypothesize that student success factors overlap with all other factors because student success is a driving force at institutions of higher education. Yet, in some cases, other factors, such as departmental culture of collaboration, might not be as crucial for sustaining innovation. Faculty enthusiasm hinges on the perceived benefit from the work at hand, which is often more than just monetary compensation (positive impacts on students, "credit" towards promotion and tenure, professional growth, etc.). Each of the factors in our model are complex entities that will vary greatly depending on the institutional environment; the necessary and sufficient elements for sustainable change vary depending on the context. Making lasting change in an educational setting is a complex undertaking, requiring the buy-in and support from many interlacing elements. As Rienholz and Apkarian (2018) imply, ignoring these interlacing elements will impact the sustainability of the desired change. We present our model as a possible organizing structure to help those seeking to implement an innovation to consider the factors that may play a crucial role in the success of their projects. In closing, we are reminded of the proverb, "It takes a village to raise a child." We could rephrase it to be, "It takes a community to support an innovation."

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