Applying Conjecture Mapping as a Design-Based Research Method to Examine the Design and Implementation of a Teaching Development Project for STEM Faculty

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Abstract
Changing teaching strategies in engineering education to become more interactive is important, though difficult. Intentional design of faculty development to engage faculty to make small, incremental changes within the context of a supportive, like-minded community, is important. In this paper, we merged two different methods to examine the PIs design decisions, and evaluate the program's implementation and outcomes. For the first method, the grant evaluator applied conjecture mapping,[1] a design-based research method, to examine the design and theoretical conjectures, the mediating processes, and outcomes of implementation of a faculty development project. The high level conjecture was that faculty who participate in a supportive teaching network will make initial small changes in their teaching, which will lead to increasingly larger changes over time. For the second method, the principal investigators (PIs) applied self-study,[2] a qualitative research method, to examine and reflect on their design-based decisions, implementation, and outcomes. Results indicated that the structures and practices supported mediating processes. Mediating processes became proximal outcomes. Medial and distal outcomes for faculty change may likely be a multi-year trajectory. Conjecture mapping and self-study proved to be useful methods in evaluating a process grant focusing on faculty change.

Keywords
Faculty Development, Design-based Research, Conjecture Mapping, Self-Study Methods, Engineering Education

Motivation and Background
There are two purposes for this paper. The first purpose is to describe our unique application of two different qualitative research methods to evaluate the implementation and outcomes for the first year of an NSF funded grant on STEM faculty development. We used two different research methods in order to be able to describe and examine adequately the underlying change processes and outcomes that faculty experienced during participation in Year One of the grant. The second purpose is to report out the implementation results and outcomes from this evaluation.

The two different research methods were: (a) conjecture mapping[1] and (b) self-study[2,3,4]. The grant evaluator used conjecture mapping, which is a method from design-based research, to examine grant change processes and outcomes over the course of Year One implementation. Then, the PIs used self-study methodology to metacognitively reflect on their initial design decisions as described by the grant and, then, as enacted through Year One implementation. The PIs also reflected on the conjecture map in terms of the described change processes and outcomes in relation to those design decisions.

Context for the Study: The SIMPLE Project
The premise for the SIMPLE project was: if faculty could be encouraged to make small changes in their teaching with the help of a supportive community, then they would make increasingly

more impactful changes over time. Hjalmarson and Nelson piloted this faculty development premise in a project with electrical engineering departments.[5] As a result of the pilot study, they developed a set of principles, the SIMPLE Principles, to guide the work of this study. SIMPLE stands for *Sustainability, Incremental (change), Mentoring, People-driven, (designed) Learning Environment.* For this grant, the PIs intentionally designed three different types of faculty learning communities. The participatory processes focused on meeting the co-constructed needs of the individuals in the community using a variety of strategies. The goal for each of the communities was to enable the faculty to enact incremental changes in their teaching in order to create more interactive learning environments for students. Thus, this grant was a design and process-focused grant.

Faculty Development as Design Science

Fundamentally, we take a perspective in this project that teaching is a design process. As Laurillard has argued, education is a design science (like engineering) in the sense that it brings together theory and practice to create solutions to problems.[6] In previous work, the PIs have explained how teaching is a design process in which the instructor examines goals and then uses a design cycle of implementation and revision to continually improve teaching. The PIs applied this assumption of teaching as a design process to the design of supporting faculty to learn about and implement new interactive teaching strategies. Thus, the PIs, considered faculty development experiences as designed processes. Drawing on design-based research frameworks, the PIs created a process in collaboration with relevant stakeholders and principles to guide the design of the faculty development group.

Design-based research examines the design sciences. A core principle of design research is the study of learning as situated within a learning ecology. We define the learning ecology in relation to the SIMPLE project a multi-structured[7] interactive system comprised of multiple elements[8] and relational processes in which a faculty member as learner develops their pedagogical cognitions and behaviors. A learning ecology includes activities, tools and resources, and the participatory and pedagogical processes in which the relevant actors engage. In a learning ecology, the processes are thought to vary systematically as a function of the reciprocal nature of the interactions[7] between the different elements of the environment and the learner as an actor in the system. Design experiments focus on the theory underlying the design, as well as, the explanations for how and why the design functioned in the learning environment.[8] In the case of our work, we were interested in understanding how the principles generated from Hjalmarson & Nelson's prior work[5] would be enacted within the design and implementation of a new set of learning communities.

Guiding principles and conjectures play an important role in design research.[8,9] Such principles and conjectures are open to scrutiny by the design research team[8] in the sense that systematic inquiry is used to examine them and revise them as the learning environment is designed and subsequently implemented. Guiding principles or conjectures present a working theory that provides pragmatic guidance to other educators seeking to create a similar or related learning ecology. Such principles are responsive to local needs and concerns and written such that they can be interpreted in multiple settings and contexts. For our study, the SIMPLE principles were designed and applied to reflect the vision for guiding principles and conjectures within design research. However, there are multiple challenges in evaluating a grant focused on the design and processes related to faculty change[10]. In this paper, we attempted to surmount the challenges by applying research methods that focus on the examination of design, process, and reflection that is, conjecture mapping and self-study.

Conjecture Mapping

Conjecture mapping is a design-based research method that is used to examine: (a) the overall design of a research project, (b) the underlying theoretical conjectures about change, (c) the mediating processes affecting change, (d) the outcomes of project implementation, and (e) the changes over time in the design, processes, and outcomes as a project is implemented. Conjecture mapping begins with a high level conjecture about how the program will work. For this project, the high level conjecture was that faculty would make an initial, small change in their teaching with the help of a supportive, like-minded community. Then, based on the support for the small change, faculty would be encouraged to make incremental and larger changes over time. This incremental change process might lead some faculty to engage in discipline-based, pedagogical scholarship. This NSF grant was developed as scale-up implementation of a successful pilot study that focused on engineering faculty's instructional changes.[5] Therefore, we wanted to determine whether the high level conjectures from the pilot study were applicable across multiple STEM disciplines and to pedagogical scholarship. This NSF grant was also developed to include a scale up related to including a faculty learning community focused on pedagogical scholarship. One key design element of this faculty learning community was for faculty to engage in self-study research about their own teaching and pedagogical change processes. Therefore, in keeping with the spirit of this faculty learning community, the PIs engaged with the evaluator in a self-study related to the design and implementation of their own project.

Self-study

Self-study methodology is a stance toward practice. Self-study acts as "a stance that a researcher takes towards understanding or explaining the physical or social world" (p. 1173).[4] Self-study methodology consists of a set of guidelines and procedures to engage in inquiry within a discipline as related to the examination of one's own praxis.[2,3,4] The purposes for self-study research are to examine self-practice in order to improve individual, program, or institutional performance[2,3,4]. Self-study research relies primarily on qualitative inquiry. For this study, the PIs used self-study as a method to examine their own design decisions, their enactment of implementation, and to reflect on initial outcomes from Year One.

Samaras defined a Five Foci framework for self-study: (a) inquiry situated in the personal; (b) critical collaborative inquiry; (c) improvements in learning; (d) a research process that is transparent; and (e) knowledge generation and presentation.[2] Samaras defined personal situated inquiry as self-initiated, grounded in experience, and using rigorous research methods to examine one's own praxis, the socio-cultural context in which that praxis occurred, and the theoretical underpinnings. However, self-study is not a solitary process. Rather, it must occur within critical, collaborative inquiry for two main reasons. First, collaborative inquiry provides those engaging in self-study a supportive and safe community to discuss, reflect on, improve, and research their practice. Second, the critical part of the collaborative community provides a means to reduce bias, supporting the validity of the findings. Thus, the peer review occurs "live" as a collaborative group engages in critical questioning, provides feedback, and suggests alternate hypotheses for researcher consideration.[2] The "critical friends" group is important to support notions related to improved learning, transparency in the research process, and knowledge generation. Given our perspective that teaching is a design process, we applied self-study to examine design decisions, praxis, and outcomes. In our study, the researchers and evaluator acted as a critical friends group.

The purpose for this study was to examine the design and implementation decisions of an NSF-funded STEM Teaching Development Grant by applying conjecture mapping and self-study as evaluative methods.We integrated conjecture mapping with self-study. Conjecture mapping provided a method to examine, explain, and visualize the workings of the trajectory of grant processes and outcomes. Self-study provided a method to reflect on initial design decisions and changes to the design decisions during implementation. Self-study also provided a means for the research team to reflect on the conjecture map and its the visualization of decision-making, implementation processes, and outcomes.

Methods

This study integrated two methods, conjecture mapping[1] and self-study[2] to examine the design, implementation, and outcomes associated with the SIMPLE project. The purposes for this study were to: (a) examine how the SIMPLE principles and the project design were implemented; (b) examine how the conjectures changed during implementation given the intended variability as defined by the SIMPLE principles[5,11]; and (c) provide a means for the PIs to reflect on their design, project implementation, and the outcomes achieved to date. In addition, this was also a methodological study in that we also reflected on the integration of the conjecture mapping and self-study as a means to evaluate a project with intended variability in its design principles to examine project implementation and outcomes.

Conjecture Mapping Methods

We applied conjecture mapping[1,12], a design-based research method[13,14], to analyze the design and theoretical conjectures as a learning ecology. For evaluative purposes, we operationalized the learning ecology within SIMPLE as guiding SIMPLE principles, the faculty learning communities, the documentation resulting from the communities. We analyzed how the tools and materials, task and participant structures, discursive practices, and mediating processes used across the study supported a trajectory of faculty development.

Self-Study Research Methods

We conducted collective self-study[16] to explore the perspectives and experiences of each of the PIs who were from diverse disciplines. Collective self-study provided the means for each PI to discuss their design decisions[17] and whether, how, and why any design decisions changed during Year One. Utilizing polyvocal self-study with the PIs promoted diverse ways of noticing and assessing the design, its implementation, and perceived outcomes.[19]

Data Sources and Analysis

To create the conjecture map and examine initial implementation, data collected during Year One of the grant were examined. Data were collected from seven faculty leaders of disciplinary groups. These data included meeting transcripts from the eight meetings the PIs conducted with group leaders during year one. During each group meeting, we distributed open ended surveys to “check-in” with the faculty group leaders to assess progress and needs. We analyzed all thirtyeight open-ended surveys. We also conducted interviews with six team leaders. In addition, we also conducted interviews with 22 of the faculty members who participated in the disciplinary faculty learning communities. Finally, we collected teaching artifacts, called design memos. The design memos documented faculty teaching changes. We analyzed the three design memos that were produced by the end of the spring semester of Year One by the group leaders.

For the self-study portion of the project, the grant evaluator or a graduate student interviewed each of the PIs at least once, one of the PIs twice and the leader of the self-study group three times. In addition, the evaluator conducted two polyvocal self-study group meetings with all three PIs to examine their reflections about the overall design of the project and what they learned from the implementation and outcomes for the first year. The conjecture map was used during the interviews as a visual means for the PIs to engage in this reflective examination. Data were coded using emic and etic analyses.[20] Emic analyses use participant language for coding. The SIMPLE principles were used for etic analyses to frame results within the language of the design principles.

Results

Initial Project Design and Implementation

The PIs designed three types of faculty learning communities: a faculty leadership community, a discipline based teaching development group, and a teaching inquiry group. The first group consisted of seven group leaders (GLs) including four white females and three white males. The group leaders represented the following STEM departments: astronomy and physics, biology, civil engineering, electrical engineering, forensic science, and mathematics. The PIs mentored the group leaders in how to lead and facilitate a Teaching Development Group (TDG). There were six TDGs in the first year. Two group leaders led one of the TDGs. The group leaders' roles were to: (a) provide a structure in which the TDG could function; (b) act as the facilitator for the TDG; and (c) model and support peer mentoring within the TDG.

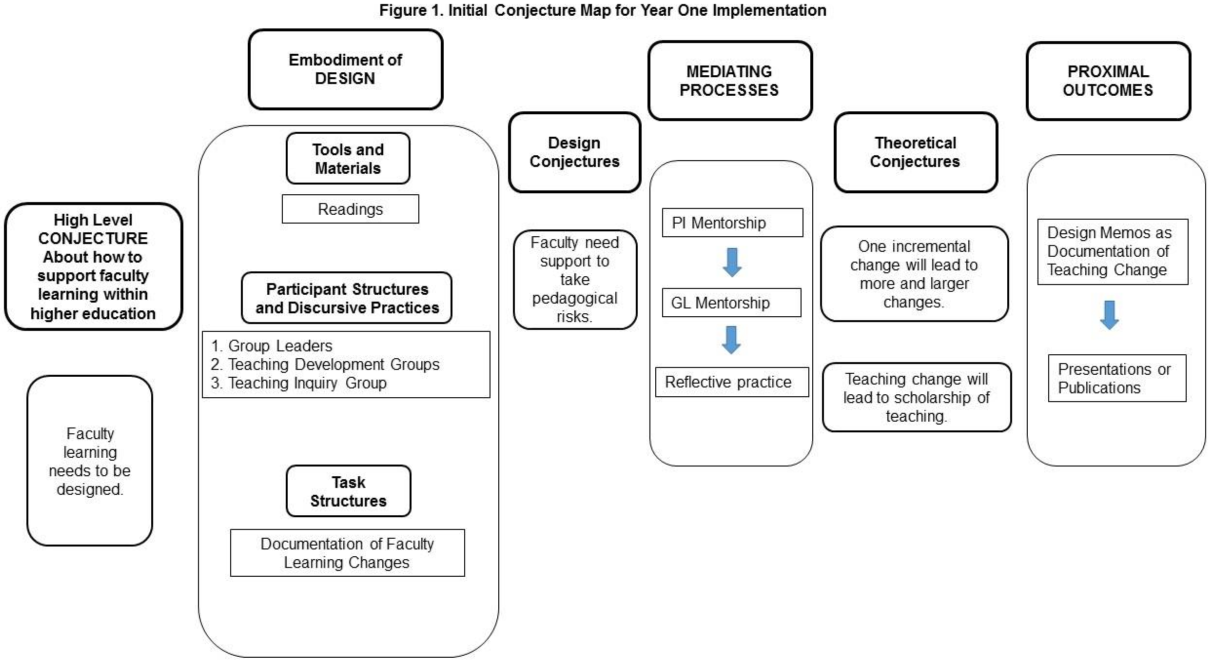
Seven disciplinary-based TDGs were formed in Year One. The purpose for the TDG was to provide a risk-free environment to discuss teaching. The goal was for the groups to consist of like-minded faculty interested in applying interactive teaching strategies within their STEM classrooms in order to engage active student learning. Thirty-one faculty and graduate teaching assistants (GTAs) participated in the year one TDGs. There were 24 faculty members and seven graduate teaching assistants (GTAs) which included 15 males and 16 females. Group members within the TDGs had opportunities to learn about interactive teaching strategies, discuss extant strategies or goals, discuss successes and failures, and learn from each other within a community. The expected outcome for both GLs and TDG faculty were memos documenting their teaching designs.

GL and TDG members who were also interested in conducting discipline-based self-study research of their teaching joined the Teaching Inquiry Group (TIG). The purpose for the TIG was to support faculty in scholarship about their pedagogy. Self-study research provided an ideal method for participants to engage in in-depth reflection about their teaching. The expected outcome of the TIG was a presentation or publication, pending the nature of the faculty member's position. All group leaders and TDG participants were invited to join the TIG. In addition, the PIs also knew of other faculty who were interested in self study of their teaching, and so, these faculty were also invited to join the group. TIG recruitment began in the spring semester of Year One and was completed in the summer beginning Year Two.

Hypothesized Conjecture Map

The high level conjecture was that faculty learning needed to be designed in such a manner as to allow the participants to drive their own learning and teaching changes. The learning ecology of the SIMPLE project included three different types of faculty learning communities as the participant structures and a means to engage in discursive practice. Thus, the design conjecture was that faculty need to be involved in a supportive, discipline-based community in order to to feel safe enough to take pedagogical risks. Mentorship and reflective practice acted as mediating processes. The theoretical conjectures were that one incremental change will lead to increasingly larger changes, and that teaching change will lead to scholarship about teaching. The anticipated proximal outcomes included documentation teaching through design memos. See Figure 1 for the Initial Conjecture Map for Year One Implementation.

Figure 1. Initial Conjecture Map for Year One Implementation



Intentional Design of Faculty Learning and Scholarship. Based on the interviews with the PIs, the SIMPLE Principles evolved over the course of Year One. More discussion was added to group leader meetings to discuss the nature of incremental change in order to help sustain a change process. The PIs indicated that peer-mentoring in a community of learners were critical aspects of the process of faculty teaching development. The sustainability element of the faculty learning communities included practical recommendations for structure in the sense that groups should create a semester-long schedule for meetings. Groups brought in outside resources (e.g., books, videos, articles) in order to provoke discussion and learn about new interactive teaching strategies.

Mediating Processes

Mentorship. The high level conjecture that faculty learning needs to be designed to allow the participants to drive the learning was implemented by the PIs for the GLs. For example, the PIs provided a semester of focused readings and discussion with the GLs to model how a TDG could function. The GL-TDG group read multiple articles and engaged in monthly discussions about teaching as design, formative feedback, and faculty collaboration. During the first year implementation of the TDGs, group discussion focused on group leader planning and progress, the role of the group leaders, and successes with the group and concerns about the group. For example in September, the discussion focused on the nature of the meetings. One group leader stated, "we plan to meet once a month." Later in the semester, group leaders discussed the nature of their interactive teaching changes. One group leader, "I ask questions… on notecards… [the students] have a choice: to ask me a question or being asked a question. And they get microphones and I call like 30 cards a session. So, it is part of the whole lecture experience." In the second semester, discussion focused on the progress of teaching development group members toward making teaching changes. The PIs also supported group leaders in developing their own design memos, implementing the interactive strategies in their own classrooms, and discussing reflections, results, and changes in teaching throughout their participation from the beginning of the grant and continuing throughout this year. Thus, the design principle of mentoring acted as a mediating process.

Outcomes

Interactive Teaching. The PIs supported group leader learning on interactive teaching by providing numerous resources related to different types of strategies on the organizational blackboard. Topics were collected during the first year of TDG implementation, suggested by participants in the GL group meetings. Topics included: immediate response systems, such as clickers, flashcards, and hand-raising; cooperative or collaborative learning; peer-assisted learning or peer-leading; the jigsaw approach; the pause procedure; flipped classrooms; demonstrations; internet interaction; formative assessment; provocative questions; and humor. This wide range of topics represented the variability in faculty choice of teaching strategy. Thus, these choice met the design principle of people-driven.

Design Memos. During year one, three of the GLs engaged in reflective practice and produced design memos. The GL design memos focused on questioning, a collaborative project, and partial classroom flipping. The goal of the questioning strategy was to improve student communication. The goal of the mini-collaborative project was to improve student engagement via topic exploration. The goal of the partial classroom flipping was to engage students in active problem-solving. In addition, the design memo structure provided an opportunity to reflect on the potential "pitfalls" if another faculty member were to implement the strategy. These were not necessarily problems that the GL encountered, but guidelines to address potential problems. For example, the GL who implemented the mini-collaborative project suggested that the strategy should be implemented in a class where a culture of collaboration has already been introduced. The GL who implemented the partially flipped classroom indicated that to avoid pitfalls faculty should provide short problems that included all of the data tables and figures to support students' ability to solve the problem. Few design memos were produced by the end of the spring semester during Year One. Faculty reported difficulties in finding time to document their changes that they had begun to implement. Concerns about whether the changes were "good enough" to be documented arose. This points to a potential change trajectory for faculty change to last longer than a single academic year, given the nature of faculty course assignments over the course of a given academic year.

PI Reflections

The PIs reflected on their initial conjectures and implementation of Year One. One PI indicated that the project was about "Learning about teaching. There is also the component of the structure about making that change. Faculty need support. [If] these groups are going to make a difference, they are about learning, but it is active learning. [The GLs] are going to try it [the strategy] out." Thus, to begin the process "one small change" was needed. Another PI indicated that she thought of the small change in the negative, that is, "Anything but small changes will lead to disaster." A PI indicated that based on the first pilot grant, they learned that community was important, "What happened in that one is that it was the same idea to create a professional learning community framework. We approached the recruitment in the same way that you recruit people who are interested from your department. Building this conversation about interactive teaching, learning more, using, and pulling those people together in a community with regular meetings." In addition, the people in the group, "should be driving how the group functions and works." The main goal for the pilot grant and the scale-up grant to STEM disciplinary faculty was, "on how we think about teaching first. Then, we can think about students [implied: in subsequent efforts]." The PI continued to explain the developmental trajectory, "faculty really need a semester to plan what they are going to do, a semester to try something out, a semester to tweak. It is really a year and a half process." Thus, PIs contend that, "it is premature to ask, 'What is the effect on student learning?', if you haven't given the faculty member enough opportunity to design something, test it, revise it, and see how it works…. The level of analysis of change is what is happening with the faculty teaching."

Discussion and Implications

Overall, the results indicated that the faculty change trajectory had begun, but that the trajectories were slower than one academic year. The PIs applied the SIMPLE design principles to provide an agile structure to support GLs. The PIs modeled the structure of a faculty learning community. The purpose was to provide guidance about the SIMPLE principles, mentor the GLs, and support the different faculty learning communities engaging in reflective practice.

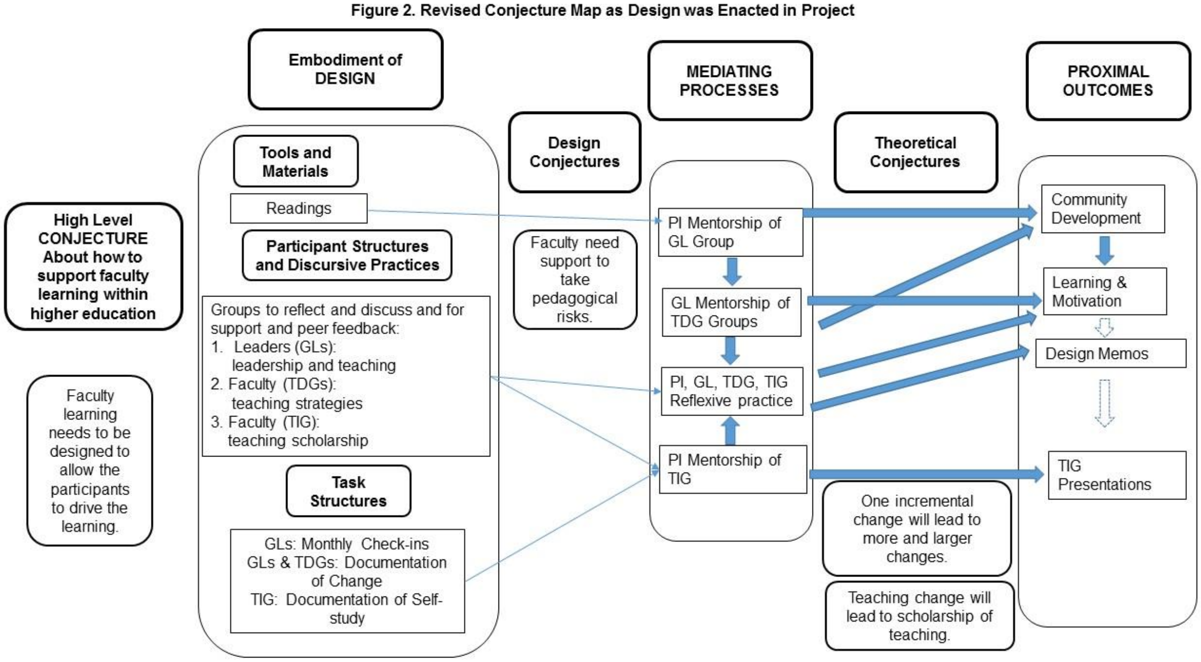
PIs required group leaders to produce a design memo as the key method to engage group leaders prior to beginning their own groups. The second key method was to require implementation of the design memo. This provided direct and recent experiences of interactive teaching and reflections about teaching that could be shared in TDGs. Group leader design memos provided a model of interactive strategies for faculty in TDGs. This approach supported the nature of an incremental change model along a developmental trajectory of faculty learning.

This process enabled group leaders a means to discuss their own process related to how various research-based, interactive practices might be implemented. This model further provided structure for self-reflection and feedback in a safe learning environment. The initial start-up meetings, orientation to topics, design memo development, implementation of interactive strategies, and discussion about the process provided affordances for group leadership in a structure, process, and a language of change.

Based on the results, we revised the conjecture model to include community as an outcome. The participant structure and the mediating process engaging in group meetings led to the development of community. Importantly, this became a proximal outcome necessary for faculty learning to occur and to support development of the design memos. Thus, the process became a proximal outcome. This is a significant finding when considering a faculty change model. That is, the processes of faculty change represent outcomes along a developmental trajectory with faculty initial, small changes potentially being a multi-year process. See Figure 2. Revised Conjecture Map as Design was Enacted in Project.

Conjecture mapping provided a useful method to model the embodiment of the intended design, the mediating processes and their relationships to proximal outcomes. In addition, PI self-study of their design and implementation resulted in rich discussion of considering mediating processes of community formation as key proximal outcomes. We found that examination of the results along with the PI reflection on their practice, the conjecture map needed to be adapted to reflect actual implementation and practice. Thus, combining conjecture mapping with PI self-study serves as a promising tool for program evaluation for faculty development projects.

Figure 2. Revised Conjecture Map as Design was Enacted in Project



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