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Exploring Complex Systems for Broadening Participation in STEM through Participatory Modeling

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Abstract: Participatory modeling is well suited for exploring and defining the complexities of a system as experienced by a full array of stakeholders. An example is broadening participation of persons with disabilities and underrepresented minorities in STEM (science, technology, engineering, and math). Funded by the National Science Foundation, the authors used participatory modeling in numerous settings, employing a variety of interactive techniques to elicit individual and group models. Using these techniques, our models resulted in more profound reflection, clarity, and descriptiveness of contributing factors. This approach also promoted inclusive and diverse perspectives because it involves the full array of stakeholders. Consumers, professionals, funders, and community partners contributed mental models to the formation of overall system models. Lastly, the resulting system model prompted focused problem-solving and discovery within groups. This paper describes the fit of participatory modeling for defining dilemmas, grappling with ambiguity, and identifying innovations around the issue of broadening participation in STEM. The authors explain their rationale for selecting participatory modeling as a methodology for addressing broadening participation research, how the approach elicited clarity about a complex system from the viewpoints of multiple stakeholders, and the overall lessons learned and challenges with the method. Examples of the interactive processes used and resulting models are included.

Keywords*:* Participatory modelling; systems change; veterans; STEM

1 INTRODUCTION

Preparing a diverse science, technology, engineering, and math-based fields (STEM) workforce by increasing the number of underrepresented minorities, persons with disabilities, and veterans, is a priority of the National Science Foundation (National Science Foundation, 2018). In 2008, the authors received funding to address ways of improving strategies and systems for supporting military veterans with service-connected disabilities through STEM education leading to STEM careers (Kansas City-Building an Alliance for New Careers in STEM (KC-BANCS), NSF Award #0929212). Drawing from the recommendations of multiple federal agencies, organizations, and scholars, the authors sought ways of creating improved higher education supports and systems. However, the authors soon realized the array of recommendations were incomplete, lacked evidence, and were not holistic.

This need for more information led to the convening of Transition STEM: A Wounded Warrior Think Tank. Eighty individuals, representing 22 states, met for 2 days to discuss the transition from military to college to careers in STEM. The results highlighted the roles of higher education, veteran services, and

STEM industry in reaching out to veterans as a valuable, STEM-ready workforce. However, the results did not provide insights into how the roles fit together to form a system support STEM education to careers for veterans, especially veterans with service-connected disabilities.

With a goal of creating a model depicting the interconnected roles and system affecting veteran success in STEM, the authors again received NSF funding (Award #1246221) to conduct a research study. Using a participatory modeling approach, fuzzy cognitive mapping, 69 veterans shared their perspectives which resulted in a model was developed and validated. Stakeholders, including military veterans, used the model for analyzing current systems and designing improvements (Jenson, Petri, Day, 2017). Due to the positive response to and utility of the model, this approach was shared and replicated during a recent INCLUDES (Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science) conference, Accelerating Data-Driven Collaboration for Large Scale Change, convened by the authors (Award #1650490). During the conference, INCLUDES Launch Pilot and Development grantees analyzed the components of their programs, the ways the components formed a system, the gaps in their system, and needs for gather further data to improve the comprehensiveness of their system approach.

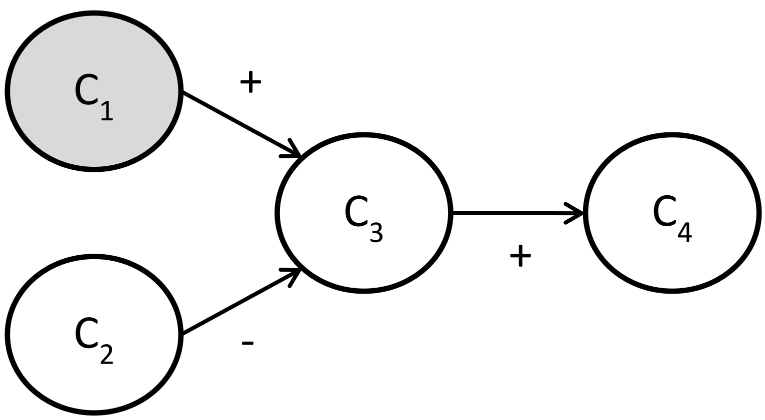
2 PARTICIPATORY MODELING

As a participatory modeling approach, fuzzy cognitive mapping (FCM) was used in each of the mentioned settings for creating a model of broadening participation in STEM. FCM emerged as Bart Kosko (1986) first proposed the method to make qualitative cognitive maps, which had originated in social science (Axelrod, 1976; Eden, 1988; Huff, 1990) computable. Through FCM, causal cognitive maps are mathematically integrated into a model (Eden, 1988; Huff, 1990). Causal cognitive maps are the mental models of key stakeholders. Stakeholders describe their perspectives and create causal cognitive map consisting of the critical factors leading to or inhibiting broadening participation in STEM. Maps include indication of the relationships between factors (positive or negative) and the strength of that relationships (ranging from very strong to very weak). With all of these pieces of information (factors, relationships, and strength), an adjacency matrix for each map is created. In the case of the study creating a model for veterans, individual maps created by 69 veterans through an interview process were integrated to form an overall model. For the conference participants, models of their programs were created collaboratively through steps facilitated by the authors.

The benefits of FCM justify the fit for better defining the issues and challenges of broadening participation in STEM (Jetter & Schweinfort, 2011; Jetter, 2003; Jetter, 2005; Jetter, 2006; Kosko, 1988). First, when data describing implementation and causal benefit is lacking, FCM provides a structure for gathering and organizing qualitative perspectives from multiple stakeholders. Second, FCM allows for integrating the multiple perspectives to more accurately portray a holistic view. Third, FCM results in a model that can be used for planning, testing hypotheses, and analyzing current system components.

The steps of FCM begin with gathering data to inform the causal cognitive map. A causal map identifies discrete factors (or nodes as used in FCM terminology) and directional arrows with +/- signs showing the relationships. See Figure 1 for an example.

Figure 1. Example of casual map



In the research study focused on veterans, this began with an interview in which the veterans described an array of factors and then created their personal map showing the relationships between factors. For each personal map an adjacency matrix was developed and matrices were then integrated to form an overall model. For the conference, project leaders were first interviewed in order to define the components of their broadening participation approach and system. Then based on identified components, a survey was administered to project staff and stakeholders as a method of gathering perspectives on the relationships between components. Based on the surveys, an adjacency matrix was developed for each program and at the conference, participants were presented with their program models.

The next step is to validate the model and make adjustments as needed. Applying a series of "if-then" questions to each aspect of the model shows aspects of the model that hold true as well as aspects needing refinement. The veterans model was validated by a group of stakeholders who reflected on each component of the model, provided interpretation across contexts, and identified gaps in the model. Based on the stakeholder input, the clarity of components was improved, the relationships between components was refined, and gaps were addressed. See Figure 2 for the Veterans in STEM overall model presented to stakeholders for validation (Jenson, Petri, Jetter, Gotto, & Day, 2018). For the conference participants, they underwent a validation process while at the conference. Because participants attended as teams, they reviewed their models, refined how components were defined, and clarifying the relationships between components. See Figure 3 for an example of model representing a program who participated in the conference. In both Figures 2 and 3, the increased size of the shape indicates more prominence of the factor in the model, the lines show relationship, and the boldness/thickness of the lines show greater weight of relationship.

Figure 2. Veterans in STEM overall model

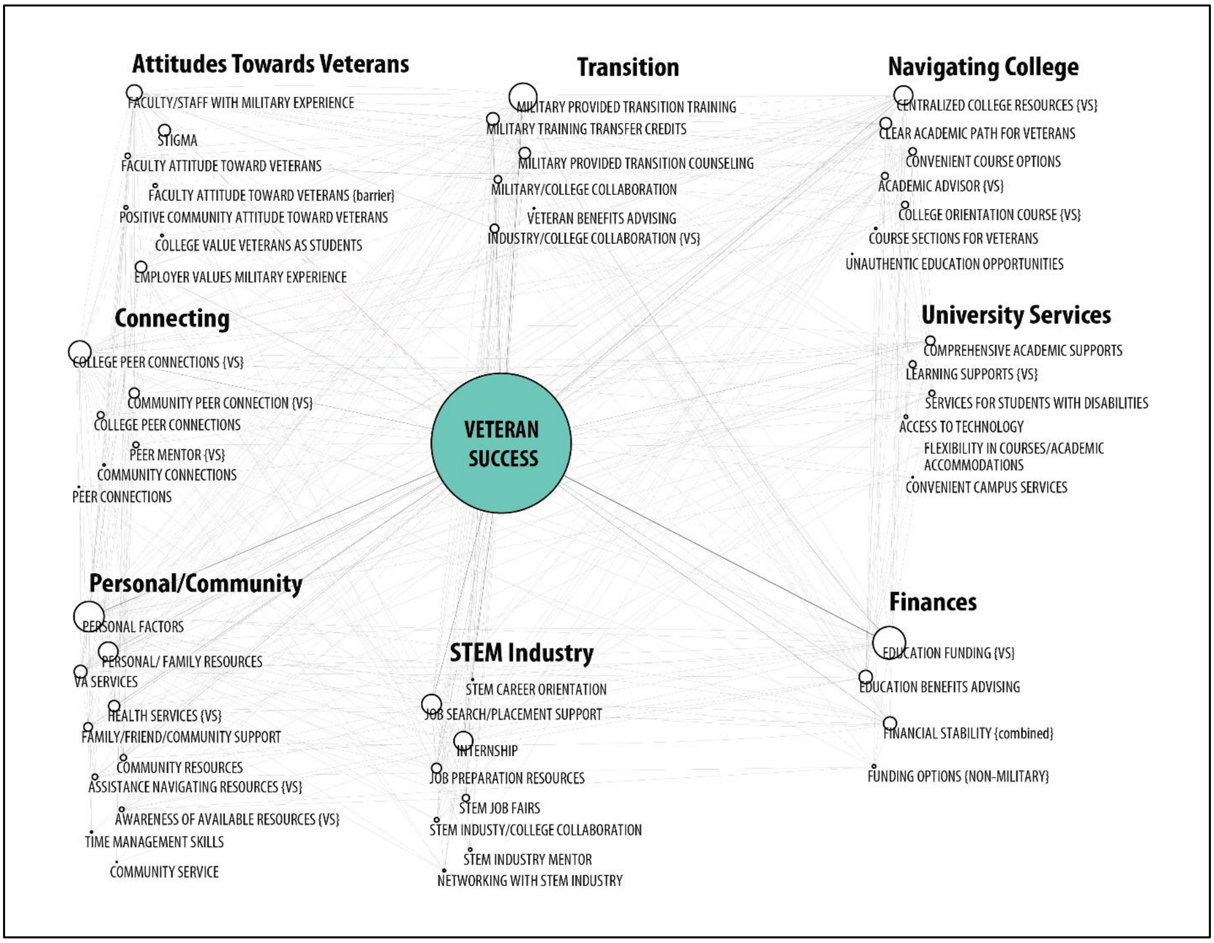
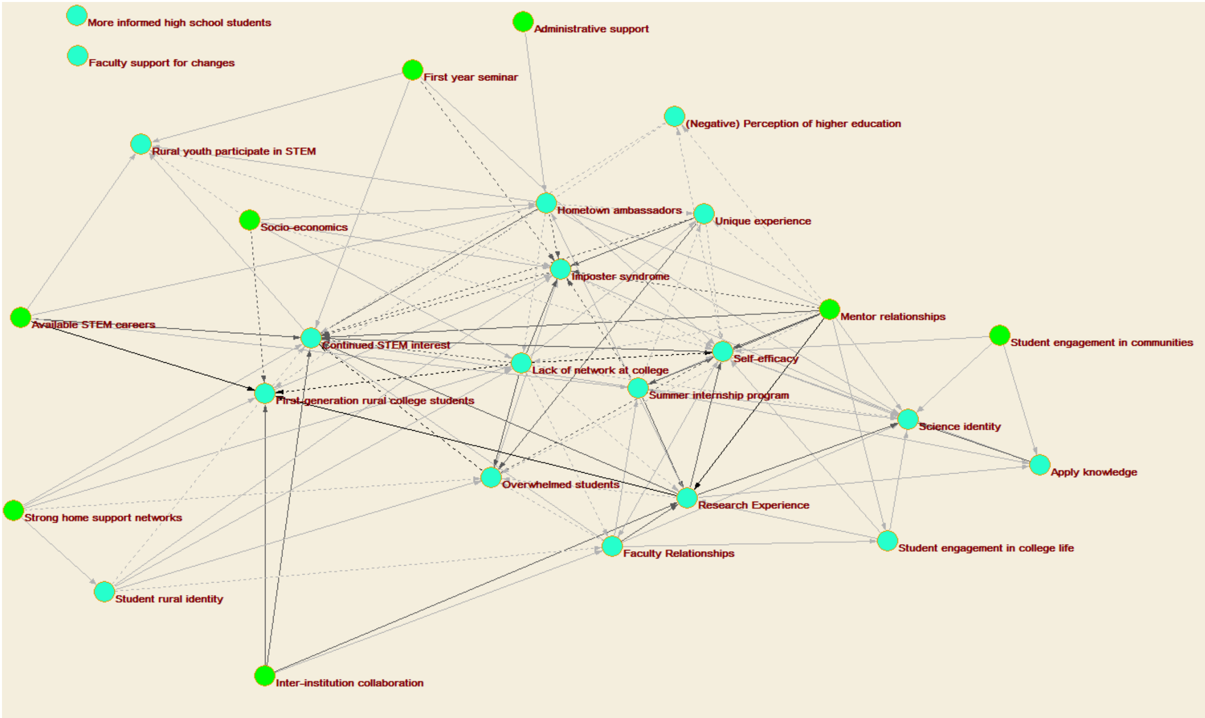


Figure 3. Example of conference participant model



The third step is hypothesis testing, or often referred to as simulations. This is a process of hypothesizing ways of improving the system, mathematically applying the improvements to the model, and analyzing results. In the case of the veterans model, stakeholders analyzed how the model responded when recommendations from the field were applied. The results showed varying levels of impact on veteran success, yet revealed critical unaddressed areas. Based on these insights, stakeholders hypothesized the most critical factors affecting veteran success and formulated a scenario consisting of high impact recommendations. When applied to the model, the recommendations showed more positive results as compared to other sets of recommendations from the field. For the conference participants, hypotheses testing during the conference was demonstrated however; due to the limited time of the conference, hypotheses testing was their homework. In follow-up with conference participants, they were able to more fully refine their models with additional stakeholders after the conference.

3 RESULTS AND REFLECTIONS

The process of developing the causal maps, for all the mentioned groups of participants, prompted rich description of the factors affecting broadening participation in STEM. As the participants identified and defined the factors, plus described how the factors are related, they critically reflected on how the factors were defined and showed intense retrospection for the relationships and strength of connection between factors.

As compared to traditional qualitative approaches, the addition of the developing the causal maps created opportunity for deeper cognition and thus resulted in more fully defined, holistic view. Additionally, the process helped individuals and teams grapple with the ambiguity of their systems. Gaver, Beaver, & Benford, S. (2003) describe ambiguity as it applies to information, contexts, and relationships. Stakeholders likely label and define the components of the system differently based on their background knowledge and personal perspectives. Similarly, the environment in which the system components exists can vary in actuality or in perception. Lastly, how stakeholders describe the connections or relationships between components are highly influenced by personal perception as well as contexts and knowledge. When integrating individual mental models or facilitating a team approach to creating a collective mental model, assumptions as to shared understanding and perspectives cannot be made. Through a systematic dialogue of describing each component of the model, the nature of the connections between components, and the qualifiers for if and when the components and connections are relevant are essential for constructing a valid representation of the system and increasing usefulness for decision-making.

The illustrative view of a system/model can be satisfying, enlightening, empowering, and daunting. From the veteran's perspective, seeing their resulting personal causal map was a satisfying picture of how they view their experiences. For the veteran stakeholders, seeing the overall model was enlightening and empowering. Many of the stakeholders had many years experience supporting veterans in higher education and the community. The resulting overall model illustrating the compiled individual veteran maps showed a holistic system that the stakeholders had known existed but were unable to fully describe. The overall model was a long awaited tool for communicating about the system supporting veterans and to plan for ways of improving the system. For the conference participants, most of whom were program leaders, their models seemed to highlight their program incompleteness and their needs for additional perspectives and data. The deeper understanding of the components and the overall model gave all of the FCM participants an improved ability to communicate about their systems of broadening participation. This improved communication is essential for gathering stakeholder support, leveraging resources, and recruiting needed collaborators.

4 CONCLUSIONS AND RECOMMENDATIONS

Using the participatory modelling approach of FCM was effective in both situations of the veterans study as well as the conference. In both cases, the process prompted deeper consideration of factors and contexts and provided a systems view helpful for decision-making and further improvement planning. However, the challenges to each situation were unique. In the veterans study, gathering and integrating individual casual maps from 69 veterans was a lengthy process. For the conference, the process was streamlined by creating the overall model from program leader interviews and follow up stakeholder surveys. By comparison, the streamlined survey approach yielded a far less complete model than the individual interview approach. However, despite the incompleteness, the resulting model was sufficient for giving participants much needed talking points for recruiting key stakeholder and completing their models at their home programs.

The participatory nature of FCM is consistent with the evidence advocating for other participatory research approaches. Partnerships between researcher and stakeholders have shown to be important for mutual learning, identifying priorities areas for research, improving interpretation of research outcomes for real world application, and creating synergy for systems transformation (Belone, Lucero, et al, 2016; Jagosh, Bush, et al, 2015). In both cases, researchers, program leaders, and stakeholders increased their depth and breadth of knowledge pertaining to issues of broadening participation. Resulting from discussion about the overall model fuelled further conversation of application in unique settings, unanswered questions for possible research, and potential solutions for improving systems.

Modelling a system through a participatory approach, whether it be the result of intentional design, organic evolution, or years of happenstance will likely reveal levels of ambiguity. Model developers should anticipate potential levels of ambiguity and tailor the model building approach to capture authentic and complete descriptions of the system components, relationships between components, and applicable contexts. Additionally, even with pre-planning the modelling approach, careful attention to data cleaning is critical. For example, if individual models are to be integrated into an overall model, differences in label and definitions of model components, as well as relationships between components must be reconciled while adhering to the individual's perception. Lastly, validating the overall model with stakeholders is important for clarity. As was discovered in the veterans study, stakeholders contributed additional qualifiers that gave valuable insight for applying the model to systems-level decision-making.

The application of FCM is growing. It is a relatively new methodology gaining prominence in the fields of engineering (Özesmi & Özesmi, 2004) , environmental sciences (Murungweni, van Wijk, Andersson, Smaling, & Giller, 2011), business (Yuksel, Bramwell, & Yuksel, 1999), and technology (Jetter & Sperry, 2013). These examples show the potential for application in education and community fields. Recommendation for use is to first consider the partnership with stakeholders and intended use of the model. For early-stage program planning and reflection, it may be most important to quickly develop an initial view of the model with a plan for subsequent refinement. The approach used with the conference participants provided an initial view and follow-up with additional stakeholders was needed in order to complete the model. If the intended use is to inform decision-making involving large-scale program improvement, then gathering a thorough model incorporating the viewpoints of many stakeholders may be most important. The veteran study is an example of an approach to gather input for a more comprehensive model. With either approach, FCM as a participatory modelling technique showed benefits for participants, stakeholders, and researchers.

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