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Abstract

Although advocacy for better science, technology, engineering, and mathematics (STEM) education has a long and distinguished history in the United States, the recent emphasis has included strong rhetoric and concomitant funding. Policy makers legislate as though STEM is clearly defined. Yet, the concept remains nebulous, which limits the nation's capacity to act in a strong and uniformed manner to address societal challenges. In this study, the authors used grounded theory methods to synthesize and interpret the federal perspective that defines STEM in the United States. The resulting theory is a model that includes five core processes: recruitment, recapture, retention, quality assurance, and quality control. These processes interact to support the system in achieving its goal of producing a qualified future workforce. Such a model has implications for advancing the overall goals of STEM as well as further research and development on the components of the model itself.

Keywords: Grounded theory; Process model; STEM education

Over the past two decades, interest in the science, technology, engineering, and mathematics (STEM) professions has increased dramatically. In fact, some would go back a bit further in time and argue that the launch of the Sputnik satellite was the event that ushered our national focus on STEM (Breiner, Harkness, Johnson, & Koehler, 2012; Sanders, 2009). Though advocacy for better science and mathematics education have a long and distinguished history, the recent emphasis on STEM has included strong rhetoric by legislators, followed by concomitant funding by the U.S. federal government. Policy makers speak and legislate as though STEM is clearly defined and well understood. However, the current environment is lacking in clear guidance and is imbued with personal opinion and the voices of special interest groups (Bybee, 2010; Herschbach, 2011; Raju & Clayson, 2011; Sanders, 2009; STEMPower, 2015). In initiatives such as the *Educate to Innovate* campaign—in which President Obama identified the national priorities as increasing STEM literacy, improving the quality of mathematics and science teaching, and expanding education and career opportunities for underrepresented groups (White House, 2009)—there is a clear sense of a national driving force, signifying that we are in the midst of a STEM movement (National Science Board [NSB], 2007; Thomasian, 2011).

Table 1
Data Sources by Category With Illustrative Examples

Category	Number	Examples
Report issued from the federal government	29 (28%)	National Science and Technology Council, Committee on STEM Education. (2013). *Federal science, technology, engineering, and mathematics (STEM) Education: 5-year strategic plan*. Washington, DC: Author. President's Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K–12 education in science, technology, engineering, and math (STEM) for America's future*. Washington, DC: Author.
Report issued by a corporation or other private entity	25 (24%)	Coble, C., & Allen, M. (2005). *Keeping America competitive: Five strategies to improve mathematics and science education*. Denver, CO: Education Commission of the States. Thomasian, J. (2011). *Building a science, technology, engineering, and math education agenda: An update of state actions.* Washington, DC: National Governors Association Center for Best Practices.
Report issued by an entity affiliated with a college or university	9 (9%)	Morrison, J. S. (2006). *Attributes of STEM education: The student, the school, the classroom. TIES STEM Education Monograph Series.* Cleveland Heights, OH: Teaching Institute for Excellence in STEM. Sturtevant, D., & Nguyen, L. (2011). *Understanding STEM education as a complex system*. Cambridge, MA: Emtect Solutions. Retrieved from http://www.micouncil.org/documents/Sturtevant_STEM.pdf
Peer-reviewed journal articles	34 (33%)	Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, 112(1), 3–11. doi:10.1111/j.1949-8594.2011.00109.x Katehi, L., Pearson, G., & Feder, M. (2009). The status and nature of K–12 engineering education in the United States. *The Bridge: Linking Engineering and Society*, 39(3), 5–10.
Websites, blog posts, or webinars	7 (7%)	Mangan, K. (2013, February 11). Community colleges respond to demand for STEM graduates. *Chronicle of Higher Education.* Retrieved from http://chronicle.com/article/Work-Force-Demand-for-STEM/137231/ Zipkes, S. (2012). The new wave of STEM-focused schools. [Webinar]. Retrieved from http://www.doe.in.gov/sites/default/files/ccr/inclusive-stem-high-schools.pdf
Total	104	

For some, the goal of STEM is nothing more than the renewed effort directed towards the literal embodiment of the disciplines that comprise the acronym. For example, Eberle (2011) suggests that the STEM movement is currently being interpreted as merely a new name for the existing, fragmented way that mathematics and science courses have been taught. However, Lantz (2009), Bybee (2010), and others are calling for STEM to take on a more robust, multidisciplinary form, as illustrated by the following quote.

> The United States needs a broader, more coordinated strategy for precollege education in science, technology, engineering, and mathematics (STEM). That strategy should include all the STEM disciplines and address the need for greater diversity in the STEM professions, for a workforce with deep technical and personal skills, and for a STEM-literate citizenry prepared to address the grand challenges of the 21st century. (Bybee, 2010, p. 996)

In order for the current STEM movement to achieve anything close to Bybee's vision, we contend that it is important to first understand the perspective and issues that define the current context. Therefore, the goals of this study were to: (a) develop a model to explain STEM in theoretical terms, (b) define and describe the properties of the model components, (c) illustrate the sociopolitical context under which the model emerges, and (d) delineate the consequences of our model for future innovation, research, and development.

Accordingly, we employed grounded theory methods to synthesize and interpret the federal perspective that underpins the current STEM movement in the United States. The resulting theory is a process model that defines and describes the core functions supporting the system. Process models are created to support the practice of design and thus have utility for creating solutions that are intended to address underlying issues (Rolland, 1998). Defining STEM in these terms affords an opportunity to advance research, development, and evaluation by moving beyond the rhetoric of why STEM is important and what it should be to better articulate it as a formal, logical, goal-directed system thereby beginning to address the problem more systematically (Confrey, 2006).

Before detailing our study, we find it important to note that the ideas presented here are not our vision for STEM. Instead, they represent the result of our use of grounded theory methods to interpret the issues and perspectives that make up the context for STEM as a national priority. Following the description of our methodology, we present a definition of STEM that was constructed through our analysis as well as our model with details on the five core processes. We conclude by discussing future research and development related to the model components as well as implications for advancing the field.

Methodology

This study used Charmaz's (2006) method of constructivist grounded theory to develop a model for STEM by interpreting the U.S. federal perspective that underpins the movement. The use of grounded theory afforded analyses that emphasized *action* and *process*, themes consistent with a movement focused on a national call to action (NSB, 2007). We used Krogstie's (2012) definition for a process: "a collection of related, structured tasks that produce a specific service or product to address a certain goal for a particular actor or set of actors" (p. 315). We began with the broad question: What defines STEM in the United States? As our analysis progressed and our definition of STEM was refined, the following questions emerged and provided additional focus for our work:

- What basic processes compose STEM?
- How are the processes related to one another?
- How are the processes related to the perspective that STEM is a solution to a problem?

Data collection was guided by the logic of theoretical sampling: Namely, we began with an initial set of documents, developed our theory, and then strategically sought out additional research and resources to further refine the theory (Creswell, 1998). For example, we began data collection and analysis with a formal writing task in which we reviewed a collection of references that included federal reports (e.g., President's Council of Advisors on Science and Technology [PCAST], 2010), websites of STEM coalitions (e.g., Triangle Coalition), federal statistics (e.g., NSB, 2010), and a special issue of *School Science and Mathematics*, an educational research journal, that focused on STEM (Johnson, 2012). Individually, we selected subsets of these sources and constructed two detailed arguments: a pro-statement defining STEM and a con-statement arguing against it as a unifying theme. These writing samples were reviewed and synthesized into our initial set of codes, which included collaborations, project-based learning, socioscientific issues, effective pedagogy, policy, applications, multidisciplinary, lack of participation, accountability, integration, literacy, and technical skills.

Data were limited to published and publically accessible documents and reports prior to 2014 from reputable public and private sources as well as articles from peer-reviewed journals that addressed STEM explicitly (Table 1). Chronologically, the earliest data source used was a 1993 publication from the Scale and Effects of Admissions Preferences in Higher Education (SEAPHE) project at UCLA titled *Undergraduate Science Education: The Impact of Different College Environments on the Educational Pipeline in the Sciences* (Astin & Astin, 1992). The majority of data sources were published in 2011 (23%), and as a supplement to this article, we have provided a reference list for the 104 sources that were used in our analysis. With respect to the information contained in our sources, we focused on identifying: the parameters, authority, and meaning from the perspective of various participants and stakeholders; the missing and implicit messages; the intended audience and beneficiaries; and how this information might affect action (Charmaz & Mitchell, 2001).

We considered all data to be situated in a context and used them as objects for analytic scrutiny by dissecting the purposes, authors, and how they were produced (Charmaz, 2006). Each datum was identified by applying our criteria to search results from the Internet, academic research databases (e.g., EBSCO, Academic Search Premier), and a review of the cited references in existing documents. For example, our analysis of the initial sources revealed two pivotal documents produced by the President's Council of Advisors on Science and Technology (PCAST), Prepare and Inspire (2010) and Engage to Excel (2012). These documents first established the problem of a projected lack of human capitol as a national issue and then articulated the federal response for improving K–12 and higher education, respectively. The frequent citation of these documents in subsequent reports led us to focus explicitly on the role of federal policy.

Data were collected and analyzed, and the results were used to refocus on the collection of new data. Following the method of grounded theory, our research problem continuously shaped our analysis. For instance, after having read Mertens and Hopson's (2006) argument for the use of a social agenda and advocacy in evaluation, it was clear that our description of the quality control process needed to be expanded not only to address the people leaving the system but also to include formative elements during matriculation that feed back into the system. The work of Mertens and Hopson (2006), as well as the other articles in a special issued dedicated to issues of evaluating STEM projects, provided the characteristics for adding a fifth core process to our model, quality assurance: "to provide the information required to indicate whether the process and structures through which outcomes and services are produced are operating effectively, and to provide recommendations on ways in which these processes can be improved" (Cuttance, 1994, p. 102).

A constant comparative method formed the foundation of our analysis (Strauss & Corbin, 1998). We engaged in an ongoing conversation over approximately three months that focused on identifying and evaluating existing and emerging evidence in relation to our argument for a process model and our rationale for the distinction among the processes. The heuristic for our approach, which was consistent with the algorithm provided by Taber (2000), involved seeking data, describing the perspective and processes that were being illustrated, addressing our fundamental questions about what was happening, and then developing theoretical categories in order to understand the information presented in each document (Charmaz, 2006). Each round of coding and discussion focused our analysis and advanced our theoretical sampling.

Analysis Heuristic

Our analysis proceeded through three phases of coding: open, axial, and selective. Data were first open coded based upon emergent themes. Examples of open codes included: developing technical skills, preparing for future employment, and using strategies to increase achievement. In order to establish the properties of individual codes, each new data source was compared to the previous data source. Open coding led to two key decisions related to the direction of our research: (a) our explicit focus on the role of the federal government in shaping the definition of STEM and (b) our choice to use STEM education synonymously with STEM. Our explicit focus on the role of the government was based upon our recognition of the historical emphasis of federal policy to introduce change in a system in order to create a more literate, competitive, and employable citizenry while addressing a host of national problems (Atkin & Black, 2003). Our decision to use STEM as a synonym for terms such as STEM education arose from our finding that the terms were consistently used across all documents with one or more of the following concepts: an educational problem (Kuenzi, Mathews, & Mangan, 2006), an educational solution (Coble & Allen, 2005), or an education-related outcome (National Research Council [NRC], 2011).

Axial coding involved clustering codes and creating categories such as goals, target audience, and example initiatives. During this phase, we developed our working definition of STEM, which was later used as a vehicle for selective coding. As we characterized the overall activity, our emerging axial codes fell under two main categories: (a) processes related to maintaining the number and diversity of people in the formal educational system and (b) examples of initiatives (i.e., designed activities that were often funded) influencing these processes. As we reviewed the various initiatives, we identified attributes common to the processes and later classified them as possible cross-cutting concepts. In order to refine our developing model, the themes expressed in those documents were compared with previous codes and the emerging characteristics of a collection of processes.

Selective coding involved the formal articulation of the core processes and an initial model to represent our developing theory. Resulting from our analysis, we constructed two formal products, a definition of STEM and a model to represent our theory that included five core processes: (1) recruitment, (2) recapture, (3) retention, (4) quality assurance and (5) quality control. As cycles of data collection and analysis were completed, these products were assessed and refined. Thus, our emerging theory guided our ongoing data collection, which served to focus our research and enhance our theory (Taber, 2000). For example, we tested our assumption that all STEM initiatives could be characterized as having a primary focus on one of the five core processes by comparing the model against abstracts for funded projects under the Mathematics and Science Partnership (MSP) program of the National Science Foundation. Finally, we addressed theoretical saturation by presenting our findings in two separate professional venues. Figure 1 illustrates our analytical method by defining the elements of recruitment as one of the five core processes.

Research questions	Example codes	Categories	Defining elements of recruitment
What defines STEM education in the United States?	Developing technical skills; Preparing for future employment; Using strategies (i.e., inquiry, PBL) to increase achievement; Emphasizing mathematics and science education; Providing authentic experiences (e.g., internships, research); Inconsistently executing in K–12; Fragmenting into separate disciplines; Inadequate preparation for postsecondary study; Lacking initiatives utilizing research-grounded strategies to increase presence of underrepresented students	Goals	Increase diversity of those in professions; Create positive identities; Defy prevailing stereotypes about who can succeed; Prepare all students to be literate citizens; Prepare students for postsecondary study
		Target audience	Pre K–12 students; Students entering undergraduate studies; Underrepresented students
What basic processes compose STEM?	Seeking students, encouraging to pursue study; Using engaging instruction to increase underrepresented students' access; Curricula connect to society's most pressing relevant issues; Offering students financial incentives and extracurricular resources	Curriculum & instruction	Integrated/interdisciplinary; Coordinated sequencing of subjects; Sustained instruction; Problem and project-based; Cooperative and collaborative; Infuse technology; Emphasize formal and applied/practical knowledge
		Current initiatives	Inclusive high schools; IL Mathematics and Science Academy; NC School of Science and Mathematics; Summer bridge programs; Project Exploration; Youth Exploring Science (YES); Early College high schools; Meyerhoff Scholars
How are the STEM processes related to one another?	Offering tracks for focused career and technical education; Decreasing time taken to earn college credits; Bolstering readiness through bridge programs; Offering extended-day activities; Mentoring with professionals	Enduring issues and questions	Transparency and accessibility to support scaling and R&D; Need for academically advanced courses in focused schools; Significant financial support for postsecondary study to offset low-income background.

Figure 1. An illustration of the analytical method from research questions to articulation of the defining elements of the process of recruitment.

We begin our discussion of results with the constructed definition of STEM, one based upon a core idea from our analysis, that STEM is an ill-defined solution to a national problem. This is followed by a description of the five core process model in which each of the processes is detailed and we explain our ideas about relationships among them. Finally, we conclude by discussing future research and development on the components of our model as well as implications for advancing STEM.

Results

STEM Is a Solution to a Problem

Highly technical jobs require an ample supply of qualified workers. Because the projected future demand for such jobs outpaces the limited supply of qualified workers, STEM is espoused as a solution to this problem (Coble & Allen, 2005; National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007; Lewis, 2006; Association of American Universities, 2006; Business Roundtable, 2005). In order to sustain economic growth, national security, an informed electorate, and endure as a global leader, the United States needs to further develop and maintain a qualified workforce (Obama, 2011). Economic analysts forecast that the United States will need one million more STEM graduates over the next decade (Langdon, McKittrick, Beede, Khan, & Doms, 2011). These graduates will be working in careers that are difficult to predict, largely due to the influence of technology, and this ambiguity has contributed greatly to the confusion and seemingly lack of focus for STEM. However, there is high confidence that these careers will include K–12 teachers, scientists, engineers, technicians, health care professionals, and higher education faculty (Sommers & Franklin, 2012). According to reports such as *Rising Above the Gathering Storm* (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007), the economic, technological, and general well-being of the United States is dependent on educational programs that can prepare engineers and scientists for today's innovative and dynamic global economy. Therefore, from a U.S. federal perspective, the goal of STEM is more accurately described as a movement to increase the volume and quality of individuals ready to enter STEM jobs. Though the metaphor is debated (Sanders, 2009), STEM is often described as the pipeline that makes this volume and quality possible (Astin & Astin, 1992; Kuenzi et al., 2006).

The current federal solution to the problem that exemplifies STEM is a goal-directed, long-term systemic strategy utilizing policy and economic incentives to guide and enact a response to the evolving issue (NSB, 2007; Obama, 2011). The goal is a sustainable system that produces and maintains a qualified workforce (Carnegie Corporation of New York/Institute for Advanced Study, Commission on Mathematics and Science Education, 2009; NSB, 2007). Therefore, we offer the following as emergent from our analysis, a definition of STEM that we use synonymously with STEM education:

> **STEM** is an enterprise focused on maintaining an adequate number and diversity of students who are in good standing and pursuing a formal academic credential in a field involving the use of science, technology, engineering, or mathematics.

This definition is grounded in our data and has been modified over time as our theory developed. For example, our use of the word *enterprise* is intended to avoid the limitations of the pipeline metaphor (Mervis, 2012) while recognizing that this difficult undertaking includes a collection of disparate entities, requires bold initiative, and involves a degree of risk. Also, we propose that the economic climate influences the visibility of STEM, but the enterprise is defined by government policy emerging as output of the political system. Thus, STEM is a sociopolitical entity that is based upon a problem with social ramifications and influences but is also defined and funded through the U.S. political process. The emphasis on the formal academic system and credentialing is consistent with the role of U.S. government but also recognizes the importance of formal learning for supporting our capacity to innovate (PCAST, 2010). Further, a highly educated populace serves the system in two ways: It addresses the problem of an underprepared future workforce, and it also ensures a more educated electorate that is capable of understanding their needs and using their votes to support elected officials that favor maintaining the focus and funding. Our broad and somewhat vague definition for "a formal academic credential in a field" is purposeful and recognizes the ambiguity of projecting future jobs. Thus, the emphasis for a national movement has to be on producing credentialed people for future jobs, not simply qualified people for current jobs (Kuenzi et al., 2006).

The Five Core Process Model

Figure 2 is a representation of our grounded theory, the five core process model of STEM. This model recognizes the enterprise as consisting of five core processes: recruitment, retention, recapture, quality assurance, and quality control. The model is based upon the enactment of STEM as a function of the formal educational system, consisting of the two primary components, pre-Kindergarten through Grade 12 (preK–12) and higher education (13–20+). The form of the model is partially dictated and defined by the constraint of time and age in the preK–12 component, meaning that once students advance beyond a defined age range they no longer have access to that component of the system. However, assuming that an individual meets the admission requirements, higher education remains open, regardless of age. For the five core process model, this implies that the preK–12 component is linear and strictly defined by age and time but the higher education component is nonlinear and less constrained. The constraint of age underlies the distinction between the processes of recruitment and recapture and how they are applied within our model. The process of *recruitment* emanates from our assumption of a single, first-time career focus and is applicable from preK through the first years of undergraduate education. By defining higher education as including the Grade 20+, we recognize its role across the lifespan for just-in-time training as well as longer term career and workforce education. The process of *recapture* emphasizes the intent of bringing people into the system who are currently involved in another career. The processes of retention, quality assurance and quality control are integral and applicable throughout the enterprise. Table 2 provides an overview of the participants, emphasis, interventions, and programs for each process that are then described in greater detail in the following sections.

<table>
<tr><td>Educational System</td><td colspan="3">PreK–12</td><td colspan="3">Higher Education</td></tr>
<tr><td>Grade Level</td><td>PreK</td><td>Kindergarten–8</td><td>9–12</td><td>13–15</td><td>15–20</td><td>20+</td></tr>
</table>

<table>
<tr><td rowspan="4">Five Core Processes of STEM</td><td>Recruitment</td><td>Recapture</td></tr>
<tr><td colspan="2">Retention</td></tr>
<tr><td colspan="2">Quality Assurance</td></tr>
<tr><td colspan="2">Quality Control</td></tr>
</table>

Figure 2. A model for STEM that includes five core processes in relation to the components and grade levels of the formal educational system. The model illustrates how the processes change as a function of the current or available grade level for a participant.

Table 2
Overview of the Five Core Processes of STEM

Process	Participants	Emphasis	Nature of interventions	Example program
Recruitment	Children to young adults; preK through the first years of undergraduate education.	Fostering an interest in STEM as a first-time career.	Formal and informal educational programing, delivered outside of school hours.	Building Opportunities and Overtures in Science and Technology <http://sites.duke.edu/boost>
Recapture	Adults	Publicizing and affording STEM as a second career alternative.	Career and workforce education.	Fast Forward New Mexico <http://www.fastforwardnm.org>
Retention	All ages from preK through adult.	Maintaining the number and diversity of students.	Academic support programs targeting known deficiencies and barriers.	High Tech High School <http://www.hightechhigh.org/>
Quality assurance	All ages from preK through adult.	Using feedback from evaluation to improve the function of the system.	Just-in-time training focused on maintaining quality. Professional development.	Kentucky P20 Innovation Lab <http://p20.education.uky.edu/>
Quality control	All ages from preK through adult.	Summative evaluation of the system's ability to meet its goals.	Assessing the knowledge and skills of the graduates, the current job market and the projected opportunities.	The STEM Research and Policy Brief Series <http://www.bhef.com/publications/research-briefs.asp>

Note. This table includes participants, emphasis of each process, nature of interventions used within each process, and example programs from across the United States.

Next, we discuss the processes individually, beginning with recruitment and recapture that serve the same goal, to bring learners into STEM. Though similar, the two processes can be differentiated by the applicable range of ages, career background, and potential entry points into the formal education system. These attributes ultimately influence the activities and strategies employed in each process as well as the short and long-term options available to participants.

Recruitment

Because children and young adults enter and leave STEM over a relatively fixed age range and linear time period, the process of recruitment is unique to preK–12 education and the first years of undergraduate, postsecondary education. Recruitment initiatives aim to increase the number and diversity of people in STEM, prepare students for their future careers, and increase knowledge and achievement (NRC, 2011). To achieve such goals, students are often sought out and actively encouraged to apply to special programs, courses, and schools (Leggon & Pearson, 2009; Schultz et al., 2011).

In response to longstanding achievement disparities stratified by race and socioeconomic status (NAEP, 2009; Aud et al., 2010; National Science Foundation, Division of Science Resources Statistics [NSF], 2011), a large focus of recruitment activities has been on enhancing underrepresented students' interest in STEM (Building Opportunities and Overtures in Science and Technology [BOOST] Science Program, 2012; Project Exploration, 2013; Saint Louis Science Center, Youth Exploring Science Program, 2012). Problem-based learning and project-based learning are often promoted as instructional strategies and curriculum interventions that can serve as a tool for recruitment (Jones, Rasmussen, & Moffitt, 1997; Verma, Dickerson, & McKinney, 2011). Recruitment can occur via targeted strategies (Kaser, 2006; Means, Confrey, House, & Bhanot, 2008), including early college high schools (Early College High School Initiative, 2012; Goldberger, 2008) and bridge programs (Means et al., 2008), or through the use of specific selection criteria. At the postsecondary level, targeted recruitment often includes providing incentives such as stipends, research and mentoring opportunities, enrichment programs, and supplemental instruction to underrepresented students (Schultz et al., 2011).

Similar to recruitment, the recapture process is intended to bring adult students into STEM. With its exclusive focus on adults, a responsive recapture process is a critical component for addressing the inherent ambiguity of projecting future jobs and career opportunities. Unlike recruitment, recapture focuses on recruiting individuals who are outside of a formal education setting and beyond the linear timeframe of K–12 education.

Recapture

Recapture involves initiatives aimed at encouraging and incentivizing STEM as a means to a viable second career. Recapture is a unique process because it inherently targets nontraditional students. A nontraditional student as one who satisfies one of the following characteristics: older than a typical age, part-time student, full-time worker, having dependents, being a single parent, or being the recipient of a General Education Degree (GED) or high school completion certificate (Aud et al., 2012). Nearly 40% of all college students are classified as nontraditional (Tripp, 2011), and six million college students are 25 or older (U.S. Department of Education, Federal Student Aid, 2015). With such a large percentage classified as nontraditional, institutions and initiatives are focusing on the process of recapture, introducing individuals back into the system or providing them tools to reenter after an initial exit.

Regardless of the reasons for or point of exiting, the process of recapture provides an opportunity for reentry into STEM and the potential for employment. Fulfilling the vision of an access point for the broadest range of adults requires a degree of responsiveness. Entrance requirements, prerequisites and degree completion requirements, such as significant numbers of credit hours, all limit the number of options for participants.

The methods of recapture can vary depending on the point of reentry. The GED is a primary mode of recapture that, since 1942, has provided those who did not obtain a high school diploma with a method of gaining a high school equivalency diploma (GED Testing Service, 2012). Workforce development programs provide training and assistance to job seekers (U.S. Department of Labor, 2012). Certificate and associate degree programs are lengthier than workforce development programs, but they facilitate recapture by allowing the student to earn a credential upon successful completion (Koebler, 2012). Recapture is also appropriate for describing mechanisms for increasing the number of teachers in STEM by encouraging nontraditional learners to pursue alternative certification paths (PCAST, 2010; Thomasian, 2011).

Because of the population served, recapture is closely tied to additional STEM processes. Nontraditional students are far more likely to drop out of college because of family, money, job, or health reasons than their traditional peers (Tripp, 2011). Thus, retention quickly becomes an issue for recaptured students. It is generally regarded as cheaper to retain students than it is to recapture them (Stearns, 2011), so a concerted effort and coordination with recapture and retention is critical. Additionally, quality control studies like the Workforce Innovation Fund can assess the impact and success of the recapture processes for workforce development. For example, enhancing the GED test to better prepare students as they enter college is also part of the quality control process. Though the process of recruitment focuses on a younger audience, initiatives for recruitment and recapture can inform each other reciprocally via the process of quality assurance. While recapture and recruitment serve to attract individuals into STEM and retention serves to keep them in STEM, all three processes are often served by the same strategies and interventions (e.g., project-based learning, enrichment programs, supplemental instruction).

Retention

Although the processes of recruitment and recapture address a big issue involving the presence of people engaged in STEM, these initiatives pale in comparison to the efforts needed to keep them in STEM, especially for students from underrepresented groups (Lee & Luykx, 2007; NSF, 2011). *Retention* involves deliberate and systematic approaches aimed at sustaining student interest, achievement, and involvement (NRC, 2011). Because this process is important across the spectrum of ages and grade levels, it includes adults and young children. Retention is an often-discussed and well-recognized process of STEM (Sanders, 2009).

Programs that express a concrete vision for educating underrepresented students aim to bring a broader set of learners into advanced STEM (Means et al., 2008; NRC, 2011), create positive identities (Means et al., 2008), defy prevailing stereotypes about who can succeed, and prepare all students to be literate citizens (PCAST, 2010). Such goals are often organized around curricular changes in the school (Means et al., 2008), extended to the local community (Saint Louis Science Center, Youth Exploring Science Program, 2012), and have a specific focus such as medicine (BOOST Science Program, 2012). Retention can also be addressed by preserving highly qualified mathematics and science teachers through financial incentives, professional development, and leadership opportunities (NRC, 2001, 2010).

Quality Assurance

Retention, recapture, and recruitment can all be optimized through additional processes that provide feedback on their function, influence on each other, and effectiveness. Thus, the primary functions of evaluation are also recognized in the five core process model of STEM. According to Popham (1993), "Systematic educational evaluation consists of a formal appraisal of the quality of educational phenomena" (p. 7). According to Scriven (1991), "The key sense of the term 'evaluation' refers to the process of determining the merit, worth, or value of something, or the product of that process" (p. 139). Evaluation occurs through two distinct roles: a formative role that identifies areas where a program, teaching condition, or evaluation can be improved (quality assurance) or a summative role that judges the effectiveness of a program, teaching condition, or evaluation (quality control). Our model recognizes both processes as part of STEM.

Quality assurance refers to the continued and ongoing assessment of the operation of the processes of recruitment, recapture, and retention, including recommendations for improvement (Cuttance, 1994). Quality assurance is a mechanism for monitoring the aforementioned processes and their associated feedback loops with the intent of addressing error prevention (Confrey & Maloney, 2011). In the context of STEM, quality assurance refers to the continued feedback and adjustments to curricula (Confrey & Maloney, 2011), teacher education (Crespo, 2003; National Council for Accreditation of Teacher Education, Blue Ribbon Panel on Clinical Preparation and Partnerships for Improved Student Learning, 2010), and instructional strategies that serve to better recruit, retain, and recapture individuals (Mark, Cooksy, & Trochim, 2009). Professional development represents the primary vehicle for quality assurance of practicing teachers and administrators (Kazemi & Franke, 2003). Quality assurance is also apparent in the evaluation of STEM-focused schools, ensuring their capacity to meet their recruitment and retention goals (Means et al., 2008). The feedback provided by quality assurance often leads researchers and developers to question their assumptions about the goals and operations of the other processes, thus emphasizing the interrelatedness of the system and the utility of feedback loops.

Quality Control

Quality control is a mechanism for ensuring that an output, product, or service conforms to a predetermined specification and often takes the form of program evaluation (Popham, 1993). For STEM, quality control activities are associated with the creation of project deliverables, verification of the deliverables (e.g., curriculum, programs, instructional methods), evaluation to indicate needed corrective responses, and activity focused on process outputs. Issues of quality control include the lackluster performance of U.S. students on international comparisons of science and mathematics achievement (Gonzales et al., 2004). Additionally, the relatively poor performance of U.S. students in mathematics and science correlates to underprepared teachers, ineffective instructional practices of teachers, out of field teachers, difficulty recruiting and retaining qualified teachers, or lack of advanced coursework (NRC, 2001). Current quality control projects seek to identify the types of curricula being used in schools, the impact of interventions on student achievement, the nature of preservice education, and the current teaching workforce as well as the evaluation process itself (Mertens & Hopson, 2006). In short, quality control assesses the capacity of STEM for producing the needed workforce and includes the skills and expectations from students, teachers, principles, and policy makers.

Together, quality assurance and quality control enable the system to evaluate the internal processes as well as the products it creates. In theory, any discrepancies, inefficiencies, or issues are addressed through a feedback loop that supports corrective action. For STEM, this implies changes to the processes of recruitment, recapture, and retention. However, critical issues for both quality processes have been identified. These include a lack of well-qualified evaluators, a lack of valid and reliable instruments to measure the outcomes of interventions, a need for new methods of merging data and analyzing large data sets, limited funding for professional development related to evaluation and equity, and diversity issues (Greene, DeStefano, Burgon, & Hall, 2006; Huffman, Lawrenz, Thomas, & Clarkson, 2006; Katzenmeyer & Lawrenz, 2006; Lawrenz & Huffman, 2006). These issues represent focal points for future research and development for improving both the quality-assessment and quality-control processes of STEM.

STEM Is an Integrated System of Processes

Our model recognizes STEM as a fully integrated system in which the processes interact in a reciprocal fashion (i.e., include feedback loops). Thus, the primary process of its focus, as well as the degree to which it involves each of the other processes, can define any STEM initiative. For example, an afterschool STEM program may include activities and strategies like interest clubs (e.g., robotics club or mathematics puzzle club) designed to generate student curiosity regardless of their academic standing. Thus, for those students not engaged with STEM, recruitment is the primary process, and for those active in STEM, retention is the primary process. However, a targeted afterschool program with the primary mission of providing tutoring and homework support would feature retention as the primary process. The process of quality assurance, as a means of formative assessment and improvement, would also serve the activities of both example programs secondarily.

Examples of STEM initiatives vary widely and can include formal educational activities like courses, degree programs, and professional development as well as informal activities such as interest clubs, afterschool programs, and outreach activities. Informal events may be perceived as simply intending to serve the public good and thus not a true STEM initiative (Falk & Dierking, 2010). However, our research suggests that the focus of these events is most likely to be recruitment or recapture due to the overarching goals of building interest, promoting the enterprise and encouraging participation (though retention could also be served). For example, the National Science Teachers Association (NSTA) recognizes that learning in informal environments "promote[s] an appreciation for and interest in the pursuit of science in school and in daily life" (National Science Teachers Association, 2012, para. 1). Thus, we also define these as STEM initiatives and use the process model to interpret their activities and outcomes. Like the disciplines represented in the STEM, the processes of the five core process model are multidimensional and include procedures (e.g., curriculum and instruction, research and development) that consume resources (e.g., time, money, materials) to serve people as the inputs and outputs.

Before discussing our views on the implications of our model and the processes defined within it, it is important to consider the limitations of our research methods and perspective.

Limitations of the Study

This study was limited by a number of factors, including those inherent in the methods of grounded theory, our interpretation and application of the process, as well as the nature of STEM itself. Though we did not stipulate a specific time period, we targeted data sources from the recent past (approximately 20 years) and limited them to descriptions of the situation in the United States. Based upon how STEM is discussed in our profession and society, we assumed that it existed as a construct and purposefully excluded data that focused on proposals or personal opinions for what STEM is or should be. As an inductive process, the sense making involved in the coding of data in grounded theory relies heavily on the diligence and integrity of the research team. In our case, the tension between our use of purposeful sampling and the validity of our grounded theory was a constant presence. Charmaz (2006) describes this as an unresolved issue in using grounded theory. We addressed the tension with a combination of diligence for critiquing our assumptions, seeking feedback on our ideas from knowledgeable others outside of our research team, and a strategy of accounting for any new STEM initiative that we discovered with our model. As a problem of sociopolitical origin, we recognized that the motivation of participating entities was inherently influenced by political agenda, which is often masked in documents or policy. As part of the inductive nature of grounded theory, we identified this masking and, to the extent possible, made explicit the role of politics in the data. To this end, we relied on our use of the constant comparative method as a means of addressing the influence of politics in the substance of our theory, but the degree of success in this effort remains a limitation to our conclusions.

Implications

We view the five core process model as having broad implications across the science, technology, engineering, and mathematics disciplines as well as for each of the processes that define the enterprise. The model's potential emanates from its simplicity and seemingly straightforward connection to existing initiatives. However, the utility is more than simple face validity and affirmation of existing approaches and investments. As a representation of the interrelated processes of a system, it serves as the foundation for the construction of new theory that explicates the relationship among the processes, their connectedness and interdependence, and the relationship between the system and the context that it is situated in. Pragmatically, such a model can lead to new ways to organize institutions and society, to teach and learn, and to view and evaluate our engagement and influence on the system. It affords an interpretation of future innovations in any of the five processes for serving participants from all backgrounds. Thus, the five core process model offers utility for fostering innovation, research, and development at the federal, state, institutional, and classroom level.

Important implications result from our finding that all STEM initiatives serve one primary process as well as additional secondary processes within the model. This finding is independent of whether the intent of an initiative has been explicitly stated or clearly defined. For example, a STEM-focused high school may be serving retention without explicitly stating such. Or, this school may have been fashioned with the primary intent of serving retention but has built structures and programing that principally serves recruitment instead of retention. As such, without a clear articulation of the processes that an initiative intends to serve, the potential for a misalignment exists between the operations of a program and its intended goals. A program intending to serve retention would need to provide structures and programing that specifically target the involvement, performance, and achievement of their target student population. These forms of programming would be very different from that which might be used to serve recruitment, emphasizing enrichment, identity formation, and mentoring.

Situated in the five core process model, we contend that all initiatives should be based upon three primary components: (a) a grounding in empirically supported theoretical models; (b) an explicit conceptual framework that defines the relationship between those theoretical frameworks and existing program inputs, operations, assumptions, and external factors; and (c) a logic model or theory of action that makes explicit the reasoning and rationale for how interventions are applied and interact in producing the desired outcomes. Including these components ensures that quality assurance is an explicit component of every STEM initiative. We recognize that this perspective is becoming part of standard practice for some programs and funding agencies, such as those at the U.S. Department of Education, but a more widespread application is needed, including new coursework for graduate students as well as training opportunities for existing professionals.

We would expect that any new STEM initiative would clearly articulate the primary process it anticipates influencing and a logical theory of action—based upon what is known about form and function of that process—for how it intends to do so, including an accounting of any ancillary interrelationships among the processes. From the perspective of quality control, this implies a need for the articulation of a conceptual framework as well as the logic inherent to any proposed innovation. Such a requirement would provide a needed dual focus for serving STEM, improving the initiative's potential for effectiveness as well as the capacity for generating new theory. For example, an informal program for children at a museum has a greater potential for effectiveness if the program were designed to serve recruitment, primarily, instead of retention. Such a program could then focus resources on experiential and enrichment activities that build interest and identity instead of retention services like tutoring or academic support that maintain participation in schools.

The five core process model has implications for initiatives related to each of the included processes. For initiatives related primarily to recruitment, recapture, and retention, quality assurance needs to be a required component. Projects such as these would greatly benefit from a more explicit focus on acquiring and using data to assess and improve their operations. Recruitment activities should be more transparent and accessible (Leggon & Pearson, 2009; Mervis, 2006). Recruitment is often comingled with retention, and although this is may be rationalized as appropriate, the focus of different activities within a program should be delimitated based upon their intent and theoretical grounding so that their differential impact can be assessed. The field would benefit from documented effects for specific strategies and programmatic structures that target enrichment, identity formation, and mentoring—in particular, the effectiveness of these strategies for traditionally underrepresented populations of students. All forms of strategies and program structures should be assessed for quality control and, when feasible, appropriately scaled.

Financial constraints impede certain populations of students from participating in STEM because the cost of pursuing a postsecondary degree is often greater than other majors (Schultz et al., 2011). This issue could be addressed with new interventions that target retention and recapture of underrepresented students. Fast Forward New Mexico, a program providing free Internet training for residents who do not otherwise have access to or cannot use Internet resources, is an example of such an intervention. The program aims to provide digital literacy skills and awareness of the power of online resources to those who participate. Although these skills do not necessarily point learners toward a particular job, the project relies on a "documented link between broadband deployment, jobs, and output growth" (Fast Forward New Mexico, 2012, p. 1). In addition, diversity needs to be assessed continually as part of the quality control process. Without explicitly emphasizing diversity as a dimension of quality control, we run the risk of over emphasizing volume and throughput (i.e., sheer numbers) as the primary predictor of recruitment, recapture and retention. Initiatives for recruitment and recapture should be coupled to efforts for retention. Generating student interest is only the first step; sustaining this interest while also building knowledge and skills is challenging and can quickly become an issue (Hidi & Renninger, 2006). In turn, this implies that retention initiatives should be more tightly coupled to efforts for quality assurance, acquiring and using data to improve the likelihood of achieving their goals and outcomes.

We need to better understand how to recapture adults of all demographics back into the system, the motivations and aspirations of recaptured students, and models for appropriate, supportive educational experiences for recaptured students. Because people displaced from the formal educational system represent the largest available cache of human capitol (Tripp, 2011), recapture and retention are processes in need of research and development. Based upon their maturity, life situation, and prospective lack of success with the disciplines (Baldwin, 2009), this population of students is expected to need alternative forms of education and tight coupling of retention to recapture (Lamos, Simon, Waits, Fulton, & Bird, 2010). Further, a thoughtful application of quality assurance to a concerted effort and coordination between recapture and retention can be mutually informative for all processes.

Project evaluation for all STEM initiatives needs to include an explicit blend of quality assurance and quality control components. For example, projects need to be designed to include meaningful assessments throughout their lifespan that offer the potential for redesign. To this end, design-based research with iterative cycles of design-evaluation-redesign offers tremendous potential (Confrey, 2006; Kelly, Lesh, & Baek, 2008). Evaluation that views STEM as a system and considers the relationships among the processes would be most informative. With a systems perspective, efficiency, cost–benefit analysis, and sustainability are all appropriate metrics for assessing quality. In addition, quality assurance and control need to assess the financial impact of funded initiatives on the outputs of recruitment, recapture, and retention. All initiatives must successfully draw in and retain a volume of diverse students. Any initiative that does not account for underrepresented students runs the risk of resulting in a decrease in the overall volume of students or an unpredicted change in the type of students pursuing a credential, thus having the opposite of the intended effect.

Conclusion

Using grounded theory methods to synthesize and interpret the federal perspective, this study defined STEM as a model that includes five core processes that interact to support the system in achieving its goal of producing a qualified future workforce. Defining STEM in terms of a process model affords an opportunity to advance research and development by moving beyond the rhetoric about what STEM should be to first recognizing it as a formal, logical system that is intended to bring about an important outcome—improving the quantity and quality of the future workforce. Such a model has implications for advancing the overall goals of STEM as well as further research and development on the components of the model itself.

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