Competing Perspectives on Attracting Students to STEM Education: A Logic Model Approach

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Abstract: Consensus is growing that existing policies designed to attract students to science, technology, engineering and mathematics (STEM) education are not effective enough to meet future societal demands for innovation and technology. A recent report by the Congressional Research Service outlined the existing state of STEM education and federal policy in the United States, which offers insights into existing policies designed to increase student interest in STEM education. This paper analyzes both the policy approach and the practitioner approach, outlining different strategies taken within the classroom by teachers and outside of the classroom by policymakers.

Introduction

"Science and mathematics education was failing to foster science literacy in the population; too few undergraduates and graduates were recruited and retained to meet the nation's future needs; and the sciences recruited too exclusively among white males – thereby depriving the nation of the talents of women of all races and ethnicities, and men of color."

This quote, taken from *Talking About Leaving: Why Undergraduates Leave the Sciences* summarizes the first investigative study into STEM attrition in undergraduate programs. Since this text was published in 1997, several efforts from the government in the form of policy measures and from the states in the form of curriculum design and implementation have been taken to try to increase numbers of students interested in pursuing science, technology, engineering and mathematics (STEM) degrees and subsequent careers [1].

The United States, as a whole, falls below several other nations in math and science achievement, which is ironic given the notion the US is the leader in science and technology innovation [2]. In a study of 15-year old students, the US ranked 28th in math literacy and 24th in science literacy. Additionally, American 24-year olds rank 20th among all nations for the number of students who earn degrees in natural sciences or engineering [3].

From a practitioner perspective, *Talking About Leaving* extensively discusses how reform needs to be implemented in the classroom, starting with the STEM faculty and focusing on pedagogical overhaul of the disciplines. One approach to addressing this problem in academia has been to modify curriculum by offering structural changes to the education. The study notes, however, that "proposing structural changes can be made without threat to established modes of thought, practice, and belief. However, if a serious attempt to reduce undergraduate attrition in these majors is to be made, sooner or later, faculty will be faced with the question of how to address their collective shortcomings as teachers" [1].

This finding illustrates perhaps one piece of an overarching problem – which actually starts in elementary and middle school. K-12 students are the future; the education system conditions students with specific pedagogy on how to learn and how to be successful (measured primarily by grades). These pedagogies and practices feed the undergraduate student pool that enters US institutions, indicating the entire education system should be considered when discussing motivation to pursue STEM degrees [4].

The K-12 education structure in the US was established differently than most other nations; standardized curriculum was absent between states, which meant that students graduating had varying competencies in math, science, and other subjects. Since 2010, states have slowly been adopting a standardized national curriculum centered on either Common Core or Next Generation Science Standards (NGSS) which aims to equalize educational competencies between states. The goals of standardizing curriculum across states include establishing shared expectations, focus, efficiency, and quality of assessments. This program and process is slowly taking traction, with 36 states and the District of Columbia adopting the standards, but it will be several years before every state adapts the standards and several more until the graduating classes have had standardized curriculum since elementary school [5].

Another issue that exists in STEM K-12 education involves teacher preparation in their discipline. In the United States, 51.5% of middle school math and 40.0% of middle school science teachers did not have a bachelor's degree in the field, while 14.5% of high school science and 11.2% of high school math teachers did not have a bachelor's degree in their discipline. These staggering numbers affect quality of teaching, student role models, and general perceptions of science and mathematics from students [6].

Graduate education in the United States is funded primarily by the federal government, with support stipends channeled primarily through large organizations like the National Science Foundation and the National Institute of Health. In fact, of the nearly $3 billion in federal funding that is allocated to STEM education programs, $2.8 billion is allocated towards postsecondary and graduate education and nearly 71% given to the NSF and NIH, respectively. These institution fund graduate students, institutional research, and a variety of graduate training fellowships awarded to students across the country. The emphasis on this allocation clearly favors graduate education and research funding, indicating federal support that is aimed more towards graduate STEM education and less towards K-12 and postsecondary education [7].

Recommendations of how to proceed with STEM education in the United States have been put forth by several reports, with the most influential issued by the National Academy of Sciences (NAS), called *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* From this report, five main recommendations have been identified for STEM Education. They include increasing the supply of new STEM teachers, improving the skills of current STEM teachers, enlarging the pre-collegiate pipeline, increasing postsecondary degree attainment, and enhancing support for graduate and early-career research [8].

Within STEM motivation, practitioners and policymakers have different approaches of how to implement solutions aimed at increasing the number of STEM students in postsecondary and graduate education. The recommendations set forth by the NAS and others affect each professional differently, and this approach aims to distinguish between the varying inputs, activities and expected outputs for each profession. Given the information provided in the literature review, logic models have been developed for both the educational practitioners and the policymakers.

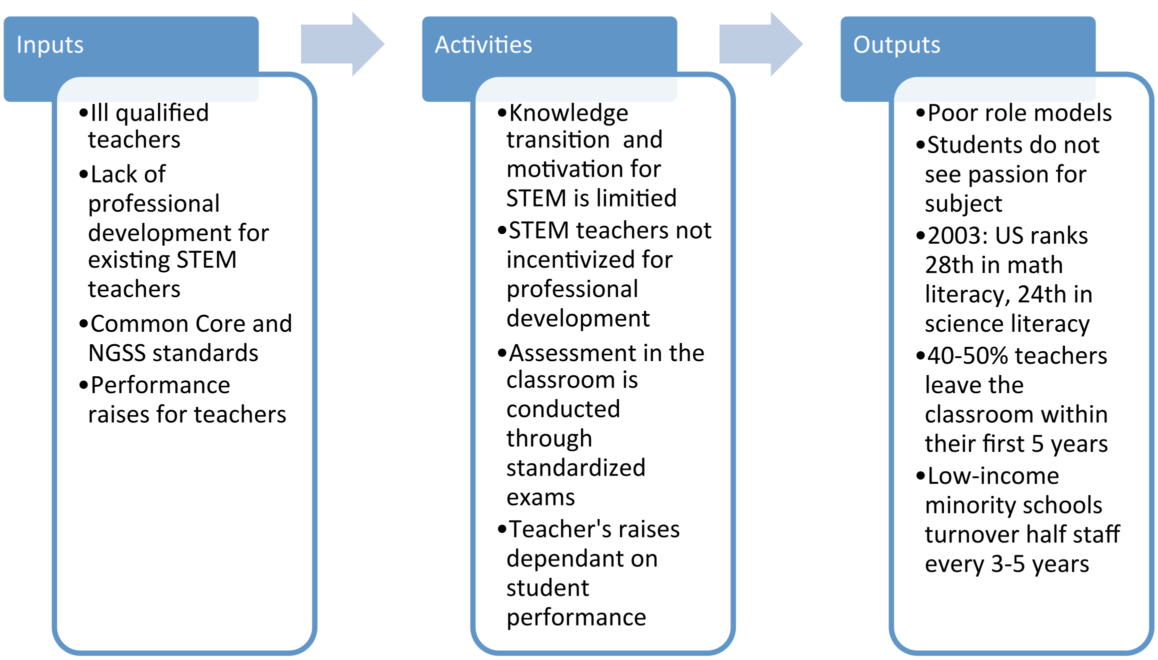
Practitioner Logic Model

The first logic model illustrates the existing environment where educational practitioners operate. Inputs for the model include teachers with ill-qualifications for teaching STEM subjects, lack of professional development opportunities for current STEM practitioners, the implementation of Common

Core and NGSS standards and wage increases based on student performance on standardized tests. Activities within this logic model include limited motivation and knowledge transition between STEM teachers and students, and assessment in the classroom conducted through standardized exams, which influence teacher's pay. This structure results in emphasizing only on what will be taught on the exam and also places stress on teachers to communicate to students exam material only.

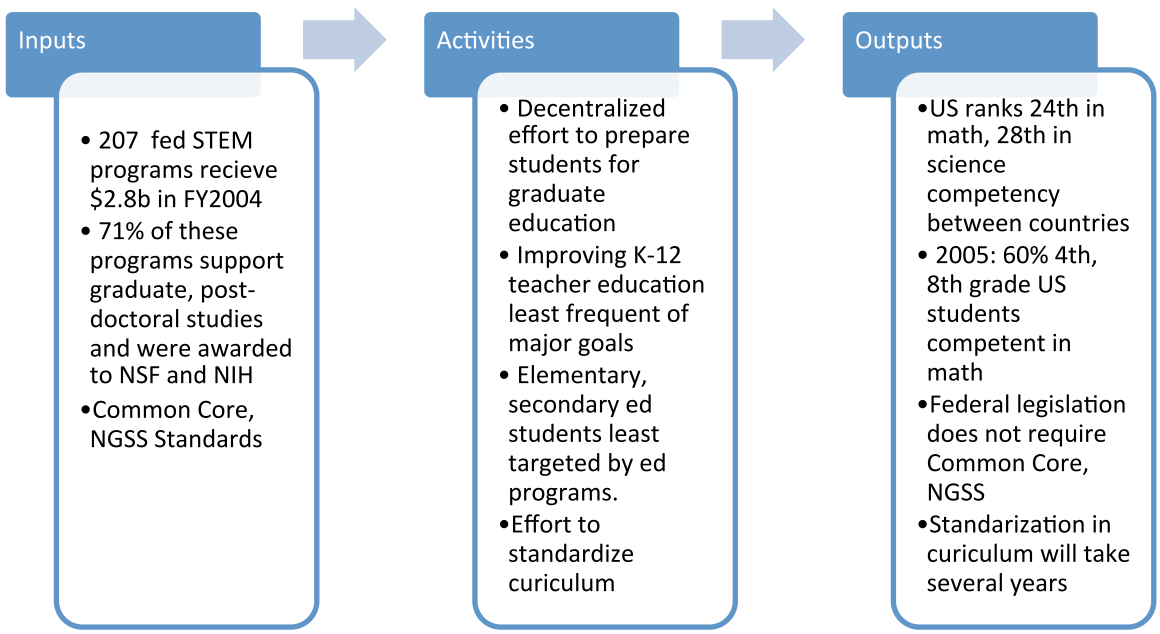
The outputs from this logic model involve both the teachers and the students. Students' preparation and ranking in the US for science and math competency are 28th in math and 24th in science for 15 year olds, with 40-50% of first time teachers switching careers within the first five years of teaching. Additionally, at low income schools half of the staff turnover every 3-5 years. The complete logic model can be viewed in Figure 1.

Figure 1: Educational practitioner logic model, outlining some of the possible contributions to motivation of STEM students from the practitioner perspective.



Policy Logic Model

The issue of motivating STEM students does not lie with the practitioners alone. Federal, state and local policy play a role in motivating STEM students. These include curriculum, funding, legislation, and implementation of passed laws. An examination of how the policy affects motivation of STEM students is outlined in Figure 2.



Inputs and efforts in the policy arena include a large federal allocation of funds, with the majority appropriated to graduate training and research. Common Core and NGSS standards aim to standardize curriculum between states, but no legislation has been passed that requires states to adhere to these standards. The policy inputs result in outputs that greatly support graduate research and education, especially if we consider where the federal government allocates their funding. Policy perhaps should address motivation of K-12 or undergraduate students, and the funding allocation from the federal government should be more distributed to meet the five recommendations set forth by the NAS report.

These two logic models offer insight into both the practitioner and the policy aspects of motivation for STEM students. This analysis and paper, however, is being written by a chemical engineer with extensive experience in fluid mechanics. As such, using an engineering analogy to describe the two pipeline of practitioner and policy for STEM motivation is useful to understand the interplay between these two pipelines.

Pipeline Analogy

Chemical engineers study fluid flow in pipes; this would include gasoline running through pipelines across the United States or oil that is shipped across Alaska on the trans-Alaskan pipeline. The equation we use to model these types of systems is represented in (1), called the mechanical energy balance.

$$\Delta \frac{v^2}{2} + g\Delta Z + \frac{\Delta P}{\rho} - W_{pump} + h_f = 0 \qquad (1)$$

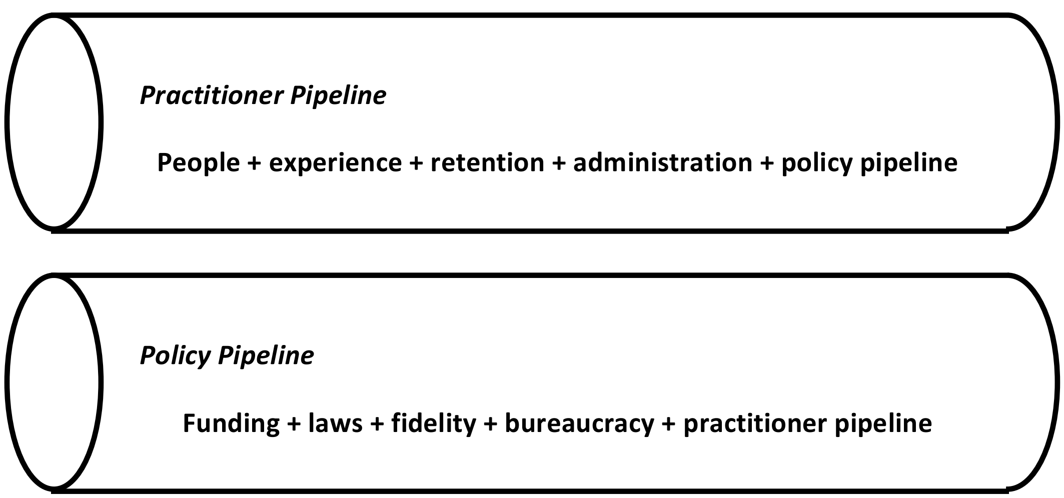
This equation has five terms, each of which relates to a type of energy that contributes to the overall energy of the system. The summation of these energies always equals zero; the first law of thermodynamics, also called the law of conservation of energy and states that energy cannot be created or destroyed only conserved within a system, is why this occurs. The first term in the equation represents kinetic energy, or the energy that the fluid contains because it is moving, like water flowing down a river. The second is potential energy; an example is water stored behind a dam. When this water is released over the turbines, the hydro energy captured is from the potential energy of the system. The third type of energy is called flow work, which represents the work done on the system by the fluid and is released (usually) in the form of heat. The pump work, W_{pump} is energy that is inputted to the system by an external pump. It has a negative sign because this energy is inserted to the system, whereas the other four types of energy are released when the fluid is flowing. The final term in the equation represents frictional losses – these include losses from the pipe wall, from fittings and bends that the fluid flows through. Most of these losses are incurred by a deviation in fluid path from a straight pipe. Fitting would connect pipes in parallel and in policy terms this would be transactionation.

These five types of energy are described in (2), with the physical descriptions used as a basis for the parallels to the practitioner and policy pipelines.

$$\boldsymbol{Kinetic\ (moving)\ energy + Potential\ (stored) energy + Flow\ work + Pump\ work + Friction} \qquad \textbf{(2)}$$

In this analogy, the policy and practitioner pipelines have been modeled as parallel pipes, with each term described by a component from the logic models.

Figure 3: Parallel pipelines of practitioner and policy involved in STEM motivation of students.



Practitioner Pipeline

The pipeline describing activities occurring within the classroom that affect motivation of students entering STEM fields is outlined in Figure 3, with each term in the pipeline describing one energy term in the mechanical energy balance. The first term, people, is analogized to the kinetic or moving energy in the classroom; the people are what influence students, ingrain passion, and communicate science and math. Their experience is the potential of this pipeline; practitioners with years of experience in the classroom know where students struggle, how to communicate difficult subjects, and can also mentor younger practitioners when they first enter the classroom. Retention is the flow work in this pipeline; flow work is where energy is released in the form of heat – retention statistics describe the number of students not adhering to a program. These “leaks” in the system are detrimental to the overall success of motivation STEM students from a practitioner perspective. The pump work is the external work inserted into the system; practitioners need support from principals, vice principals, distant superintendents and administrators across the educational system – these are the people that can invigorate the pipeline with effective practices or strip it of energy with ineffective or inefficient policies.

The last term in the equation links the two pipelines together; fittings in pipes are the pieces that connect parallel section of pipe, and by joining the two pipes together, achieving higher motivation in students to pursue STEM disciplines would results. Thus, the final term in the equation for the practitioner pipeline is the policy pipeline. The goal of the practitioner pipeline would be to conserve energy and channel it in the appropriate places. When a system is losing too much energy, engineers will examine each term to determine where the unnecessary losses are occurring. In much the same way, the practitioner community can approach the topic of STEM motivation through each individual piece, better understanding where to first channel resources to achieve the most gains.

Policy Pipeline

Structured similarly to the practitioner pipeline, the policy pipeline contains five terms that can be analogized back to the mechanical energy balance. Kinetic or moving energy in the policy pipeline is funding; the allocation of fund (at the graduate, undergraduate, or K-12) level describes priorities from policymakers, and is the energy that can affect change. The potential energy is the laws passed, which may have possibility to affect great change, but implementation and regulation ultimately decide how laws are interpreted and put into practice. The fidelity, or effectiveness, of these laws is described by the flow work, where leaks may occur within the system because of the practices changed by the laws themselves [9]. Some laws are fiercely enforced, while others are considered outdated even by politicians. The actual implementation of laws geared towards affecting change in motivation of STEM students could be leaks in the system.

Pump work, or work entering the system from an external entity, can be described in the policy pipeline as bureaucracy. This describes the willingness of several government organizations to coordinate and centralize their efforts to increase the energy in the policy pipeline. Finally, just like in the practitioner pipeline, the frictional term is the connection to the practitioner pipeline, highlighting the importance of cooperation between practitioners and policymakers to ultimately allow these two pipelines to intersect and combine their energies to increase motivation of STEM students.

Conclusion

This study acknowledges the growing consensus that not enough US students are entering science, technology, engineering and mathematical careers. The approach breaks the topic into both practitioners and policies, formulating logic models that describe the inputs, activities, and outputs associated with each. The findings indicate that activities are yielding outputs in not in alignment with stated goals; over half of new practitioners switch away from teaching after their first five years and nearly 71% of the federal budget is allocated towards graduate and research funding. These entities have been analogized to a mechanical energy balance, the equation engineers use to describe pipe flow, with both the practitioner and policy pipeline including five terms. The practitioner pipeline is: people + experience + retention + administration + policy pipeline and the policy pipeline is funding + laws + fidelity + bureaucracy + education pipeline. These descriptions construct a model that describes where energy can be lost in each pipeline, with the ultimate goal of connecting the two pipes to channel the energy towards the same overall goal of increasing STEM motivation.

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