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POLICY INNOVATIONS TO ENHANCE THE STEM TALENT PIPELINE

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EXECUTIVE SUMMARY

This report summarizes the first-year progress in a two-year study of policy innovations to enhance the STEM talent pipeline. Significant progress is reported across several tasks and themes. Four economic models of the higher education ecosystem were developed to represent financial drivers of the overall education system in terms of institutional economics, investments in STEM retention, investments in developing a skilled technical workforce, and the behavioral economics of students' decisions. The nature of student flow was addressed using available national longitudinal data sets to develop a systems dynamics model of student flow, including an assessment of student flow into the skilled technical workforce in five states. In the process, several academic institutions were addressed in detail. This report concludes with an outline of plans to address engaging and nurturing promising high school students, as well as plans to model the impacts of policy instruments on the overall talent pipeline.

INTRODUCTION

This report summarizes the first-year progress in a two-year study of policy innovations to enhance the STEM talent pipeline. This project involves five tasks pursued across the two-year plan. These tasks, listed below, are sufficiently interconnected to cause progress during the first year to include accomplishments related to the two tasks associated with the second year. Hence, this report provides a summary of the progress on all five tasks.

Year 1 Tasks

1. Development of an economic model of the higher education ecosystem to understand financial drivers of the overall university system and drivers within the research environment.
2. Talent identification and recruitment to protect and promote the domestic and international STEM workforce
3. Identification of selected universities to support their achieving preeminence in strategic areas

Year 2 Tasks

4. Engaging and nurturing promising high school students towards STEM, and perhaps national security application domains
5. Modeling policy Instruments to better understand short- and long-term impacts, both positive and negative on the US STEM Talent Pipeline

ECONOMIC MODEL OF THE HIGHER EDUCATION ECOSYSTEM

Policies are intended to have consequences on the outcomes within the targeted domain, in this case education. Achieving these outcomes requires investments

of human and financial resources. The human resources typically have associated operating costs. There is usually a tradeoff between expenditures for investments and costs, and the subsequent outcomes achieved. Succinctly, increasing the extent to which outcomes are improved requires more money. Policies are intended to have consequences on the outcomes within the targeted domain, in this case education. Achieving these outcomes requires investments of human and financial resources. The human resources typically have associated operating costs. There is usually a tradeoff between expenditures for investments and costs, and the subsequent outcomes achieved. Succinctly, increasing the extent to which outcomes are improved requires more money.

ECONOMIC MODEL OF RESEARCH UNIVERSITIES

Our efforts on this task were built upon the Economic Model of Research Universities (EMRU) shown in Figure 1. The development and applications of this model are discussed in depth in (Rouse, 2016; Rouse, Lombardi & Craig, 2018). The typical tradeoffs addressed include:

- Tuition projections over years vs. class sizes, faculty composition, funds secured, etc.
- Brand value projections over years vs. percent tenure-track faculty, salaries, etc.
- Adjustment of organizational parameters to address price competition due to technological innovations
- Adjustments of all parameters to achieve zero net present value of surplus of deficit

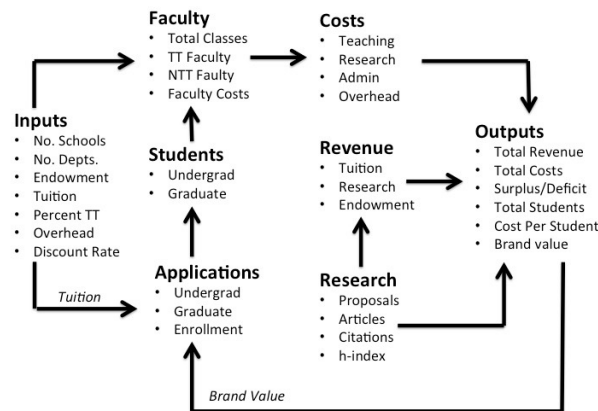


Figure 1. Economic Model of Research Universities

EMRU has been provided to over ten institutions and applied to detailed analysis of several well-known, top universities. All of the many relationships in the model

are empirically based and discussed in detail in Rouse (2016). More detail in presented in Appendix A.

ECONOMIC MODEL OF RETENTION INVESTMENTS

An Economic Model of Retention Investments (EMRI) is shown in Figure 2. This model was developed to project the economics of alternative investments in student support and process improvements to increase the retention of students enrolled in college STEM programs. Currently, roughly 50% of enrollees drop out of programs before completing them.

The at-risk population is classified as high, moderate, or low risk. The costs and effectiveness of retention investments are varied and net present returns are projected, both in terms of expected value and 95% confidence levels. A range of analyses were performed for selected universities with documented retention challenges, including Georgia Southern, Northern Illinois, University of Colorado at Denver, University of Texas at Arlington and University of Texas at Rio Grande.

The functionality of EMRI could have been incorporated into EMRU. However, it did not make sense to address the detail of STEM retention in an overall model of the total university. It would be akin to using an overall model of the US economy to assess the impacts of varying student loan programs. Models need to be tailored and tuned to specific questions on interest. More detail is presented in Appendix B.

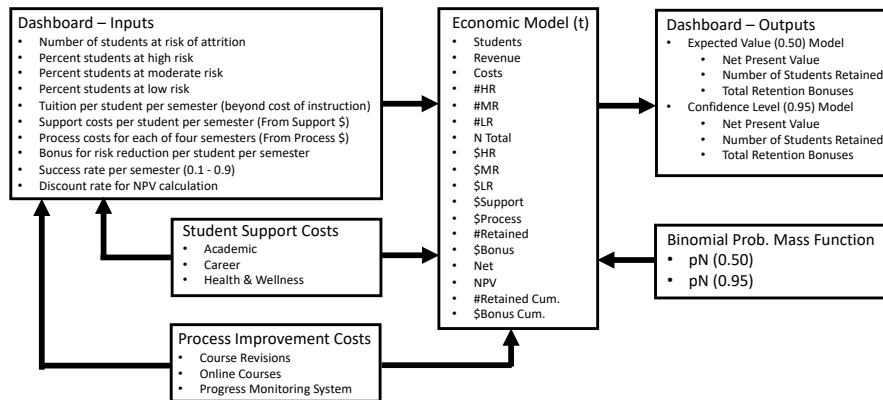


Figure 2. Economic Model of Retention Investments

ECONOMIC MODEL OF WORKFORCE INVESTMENTS

An Economic Model of Workforce Investments (EMWI) is shown in Figure 3. This model was developed to address economic impacts on integrated K-12, community college, and employer programs to meet the skilled technical workforce

needs of industry. This type of question would be rather tangential to the intent of the EMRU and EMRI. Thus, no attempt was made to pursue this question with the earlier models.

Investments from federal, state, local, and industry sources in one- to two-year programs are made to create skilled technical personnel such as electricians, machinists, and cyber security specialists needed by industries, typically within a state. We have studied this approach in CT, IN, MI, PA and SC, with overall results that are discussed later in this report.

These programs typically yield skilled workers immediately hired by industry with starting salaries in the \$50,000-\$70,000 range. These workers then become consumers and taxpayers for the next 40 years or so. The returns on these investments, as shown in Figure 3, are enormous, even when discounted to reflect the time value of returns.

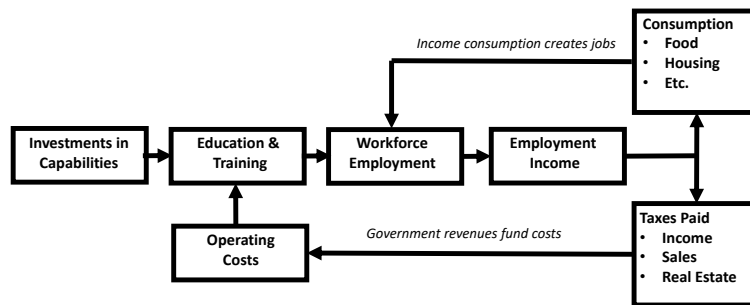


Figure 3. Economic Model of Workforce Investments

Thus, these investments are easy to economically justify. However, a fundamental difficulty limits appropriate consideration of these investments. The various cash flows due to taxes paid and consumption flow to a myriad of agencies and organizations that do not necessarily feel any responsibility for investing in training the skilled technical workforce. The inherent fragmentation of the US government, across all levels, limits strategic thinking about education investments. Considerable more detail on this model is presented in Appendix C.

BEHAVIORAL ECONOMICS MODEL OF STUDENT CHOICE

A Behavioral Economics Model of Student Choice (BEMSC) is shown in Figure 4. Each of the bullets in these five lists are based on one or more empirical studies of students' choices described in Appendix D. Many of these studies involved surveys, but several were rigorous empirical studies of choices and outcomes.

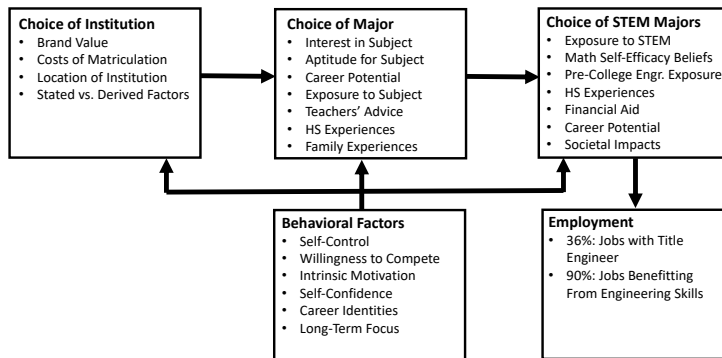


Figure 4. Behavioral Economics Model of Student Choice

The EMRU in Figure 1 assumes that student choice is driven by a tradeoff between brand value and tuition, i.e., students will choose the highest brand value institution they can afford and, of course, gain acceptance.

The choice to major in STEM and the particular discipline is much more complicated as summarized in the two rightmost choice blocks in Figure 4. Interests, aptitudes, exposure, and experiences have major impacts. We return to these observations later in this report. Considerable more detail on this model is presented in Appendix D.

DOMESTIC AND INTERNATIONAL STEM WORKFORCE

Considering workforce, it was natural to first consider the DoD STEM workforce. Figure 5 provides an analysis of this workforce. Not surprisingly, there are more hires still employed by DoD from recent years than past years. The distribution of education levels has not changed much over those years.

The percent Student and Exchange Visitor Information System (SEVIS) STEM has decreased, as has the percent engineering occupations. Computer science has increased, not surprising given technology trends, as has “other,” which includes health-related occupations. The implication is that the STEM pipeline needs to be enhanced beyond engineering.

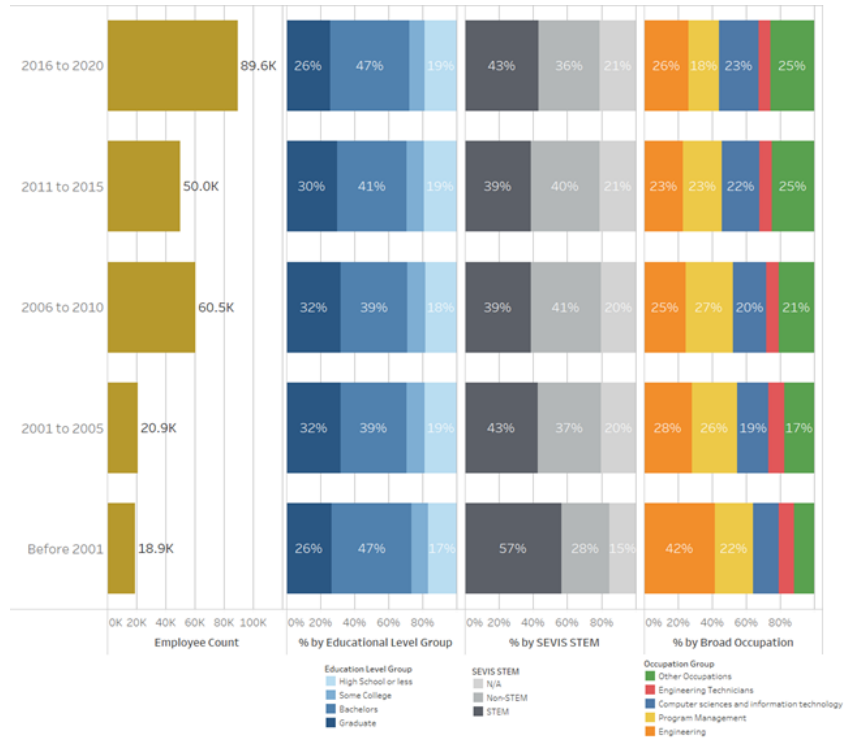


Figure 5. Composition of DoD STEM Workforce

HIGH SCHOOL LONGITUDINAL STUDY (HLSL)

This IES data comes from a nationally represented longitudinal study of over 23,000 9th graders from 944 schools in 2009. The Sankey diagrams – Figures 6a and 6b -- represent data from the first follow-up (2012), to the 2013 update, and finally to the second follow-up (2016). Figure 6a shows 2012-13 data that describes where the student went after high school, and what choice of major was selected (if at a four-year institution). Figure 6b shows 2013-2016 data that describes the flow of students during their college years. This includes major change and no college enrollment. Nonrespondent data from 2012-2013 was not included in this diagram. This data was also incorporated into the Limited-General System Dynamics Model discussed below.

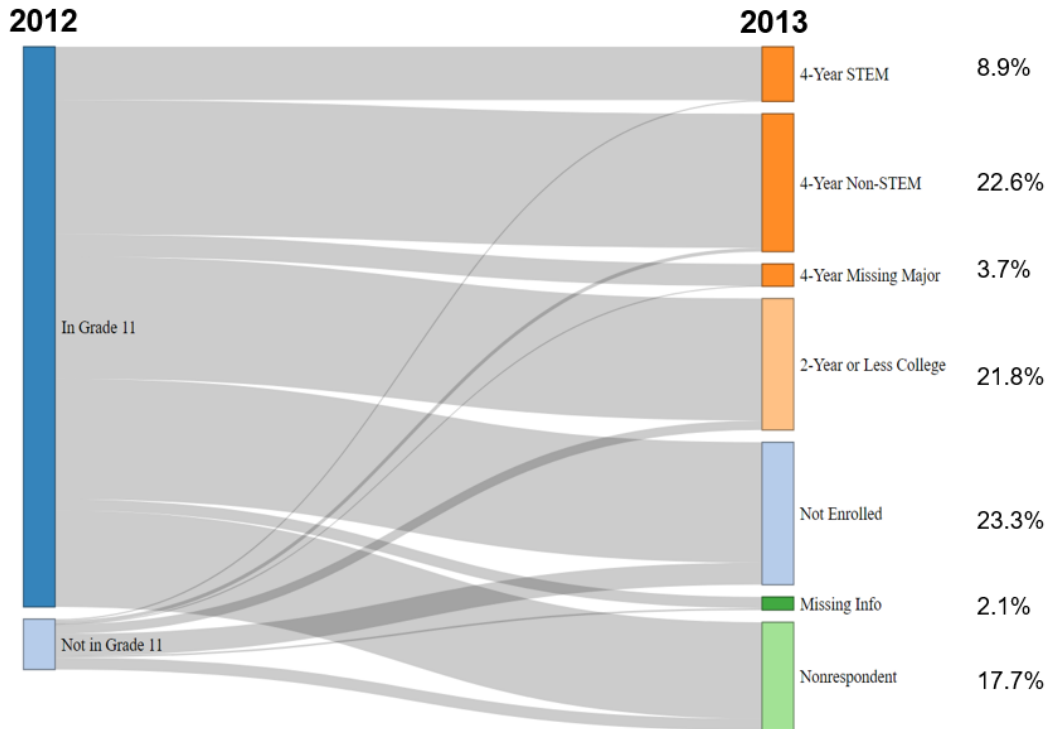


Figure 6a. HSLs Transition Data for 2012 to 2013

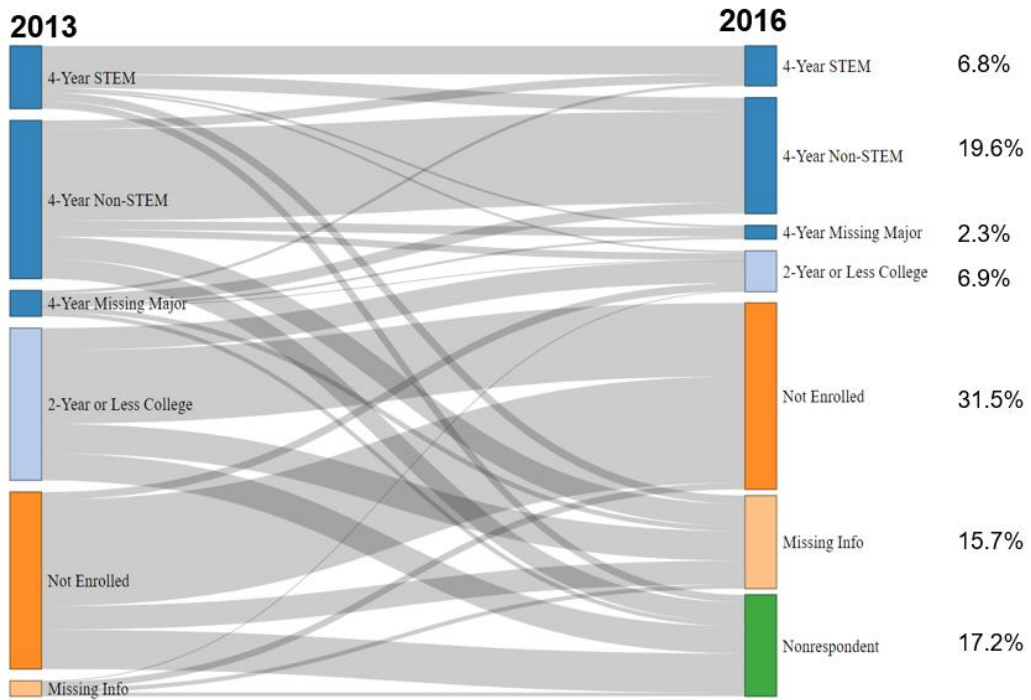


Figure 6b. HSLs Transition Data for 2013 to 2016

Some of the possible paths in the Sankey diagrams are not identified by any available data. This could be due in part to the time period represented by the Sankey diagrams. For instance, many students in 2-year programs may take longer than 2 years to complete their studies. Therefore, if the data from the Sankey diagrams represented more periods of time, they might visualize more paths from the 2-year college categories.

SYSTEM DYNAMICS MODELING

System dynamics is an approach to representing the behavior of complex systems over time. Complex dynamic behavior is produced by two types of feedback loops: reinforcing and balancing. Stocks (or levels) and flows drive the behaviors of these loops. This type of representation enables an understanding of the impacts of interactions in complex systems.

Three studies that used system dynamics modeling to address the quantities of people moving through the STEM pipeline were identified – see Figure 7a. Two studies, one sponsored by Raytheon (Wells, Sanchez & Attridge, 2010) and another by Boeing (Sturtevant, 2008), focused their efforts on identifying factors in the K-12 education system that have an impact on the number of students entering STEM fields in higher education.

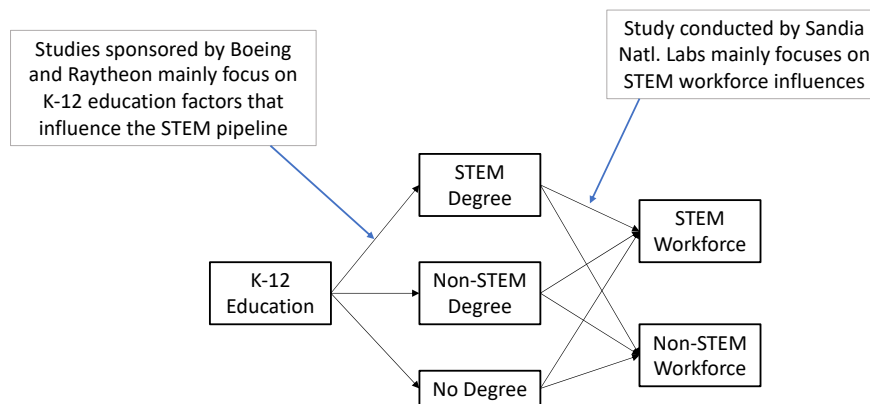


Figure 7a. STEM Pipeline & Previous System Dynamics Studies

A study conducted by Sandia National Labs focused on workforce influences that impact the number of students graduating with STEM degrees (Kelic & Zagonel, 2008). There is a lack of direct focus using system dynamics modeling on the

college education segment of the system, particularly investigating factors that impact collegiate STEM retention rates.

The models described in this document are modeled in Vensim. Vensim is a popular system dynamics modeling software referenced in many research publications including a previous study of the STEM pipeline (Sturtevant, 2008), as well as studies involving policy analysis (Saleh, 2010) and various other complex systems.

System dynamics models consist of stocks, flows, and external variables. The system dynamics models developed for this research are shown in Figs. 7b, c, and e. In these models, stocks are depicted by the blocks in the model and represent the level of a material at any given time. For this implementation, stocks are representing the number of people in a particular place in the STEM pipeline. Flows are depicted by the lines moving between stocks and represent the flow of the material moving between stocks. External variables are any of the variables in the model that are not part of the stock and flow pipeline. These variables are related to other variables, stocks, or flows through the blue arrows shown in the model. The depiction of clouds represents the sources and sinks of the flows for the model, determined by the model scope. These are where the materials studied originate from and terminate at. In the case of our models, the source is students graduating high school, and the sink is students' entry into the workforce.

Multiple system dynamics models are being developed. The nomenclature used for each models describes the scope of the problem each model addresses. The "Limited-General" model (Figure 7b) is generalized across the U.S. and has limited pathways to simplify early model development. Pathways include the "STEM Pipeline" and various places for students to drop out of the pipeline.

The model shown in figure 7b is a preliminary version of the limited-general model. The purpose of this prototype is to demonstrate the functionality and scope of the model with prototype variables. The variables selected for this version of the model are chosen based on their expected contribution to the STEM retention rates the model is studying.

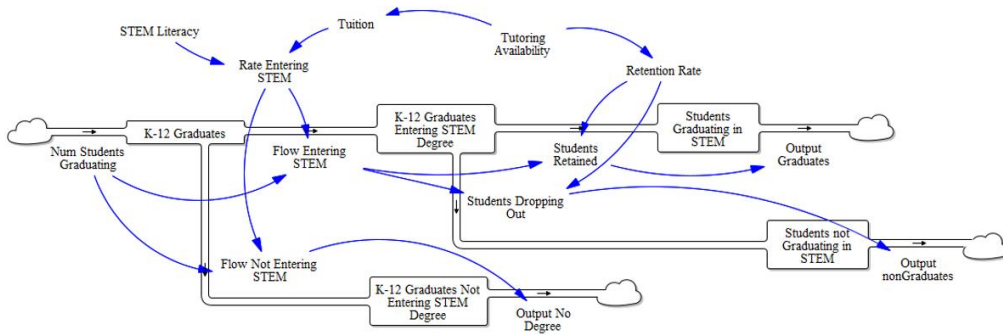


Figure 7b. Limited General System Dynamics Model

The “Full-General” model includes more pathways for a more realistic model. Added pathways include options for students to enter a STEM program, non-STEM program, or not enter college. There are also options for students to re-enter the STEM pipeline after falling out of it. Limited-Specific and Full-Specific models will eventually be created which are built off of data specific to Purdue University.

The full general model will provide a more realistic result as policy changes are studied with the models. However, as new policy changes are being tested, the limited-general model will be useful to test additions to a simplified version of the model before implementation in the full-general model.

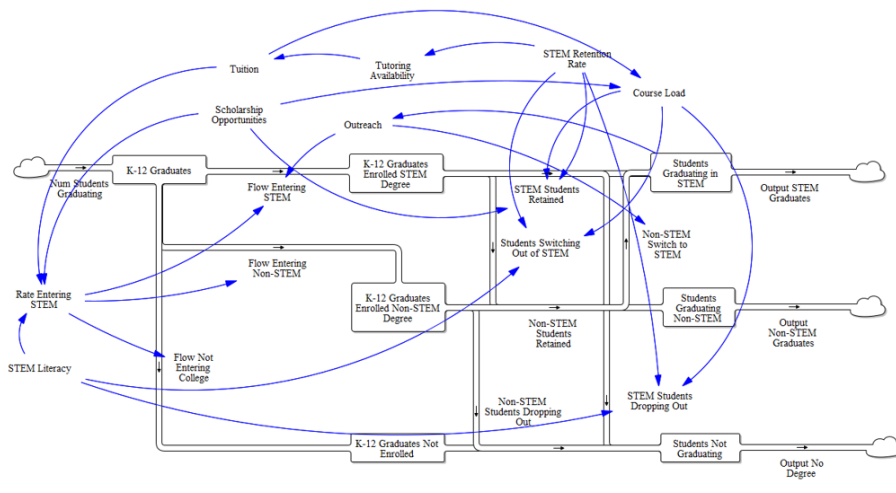


Figure 7c. Full General System Dynamics Model

Regression data is initially incorporated into the model by sorting students by demographic for each instance of the simulation. Based on regression data derived

from the HSLs national dataset, discussed above, values are assigned to a set of driving factors for each demographic (Figure 7d). An instance of the model is run for each demographic, and results are generated in the form of trends seen in college retention rates as driving factor values are altered.

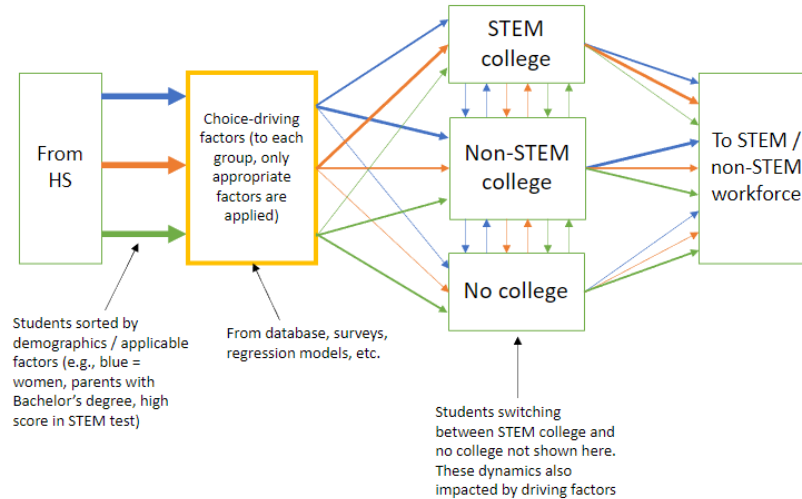


Figure 7d. Incorporating Regression Data

The system dynamics model shown in Fig 7e is the current working version of the full-general model. The flow of students through the model is determined by factors dependent on the demographic factors chosen for a selected population. Results are generated for 3 different sample inputs, with each sample input representing a different population demographic.

The sample demographics used are 1) female students who have parents with a STEM degree, 2) male students who grew up in a rural environment, and 3) Asian males. Each of these sample demographics come from a combination of factors that were determined to be statistically significant from the HSLs dataset. The driving factors for each of the demographic characteristics are defined and input into the model. The model is then run for each demographic. Outputs of the percentage of students graduating with a STEM degree is plotted and shown in Fig. 7f.

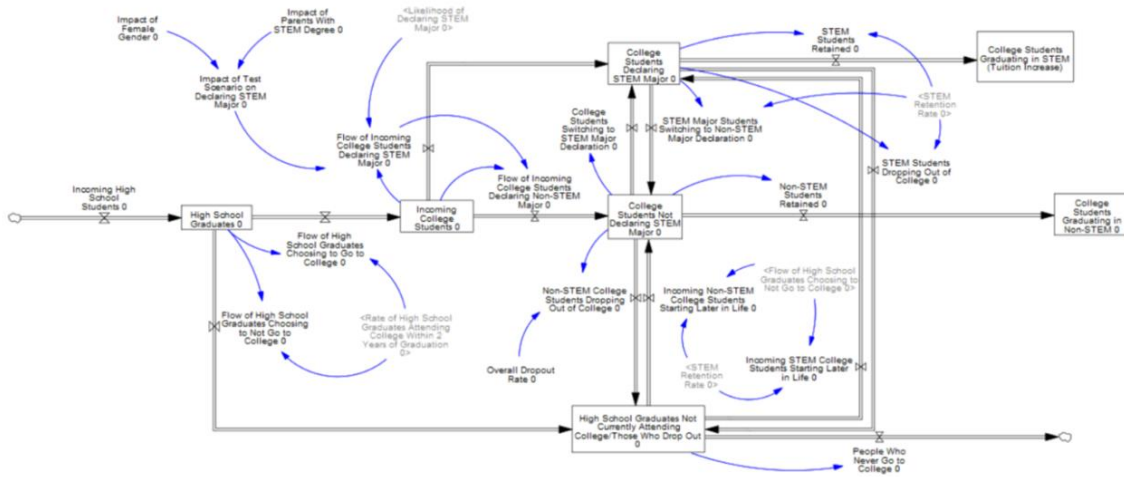


Figure 7e. Full-General System Dynamics Model Implementation

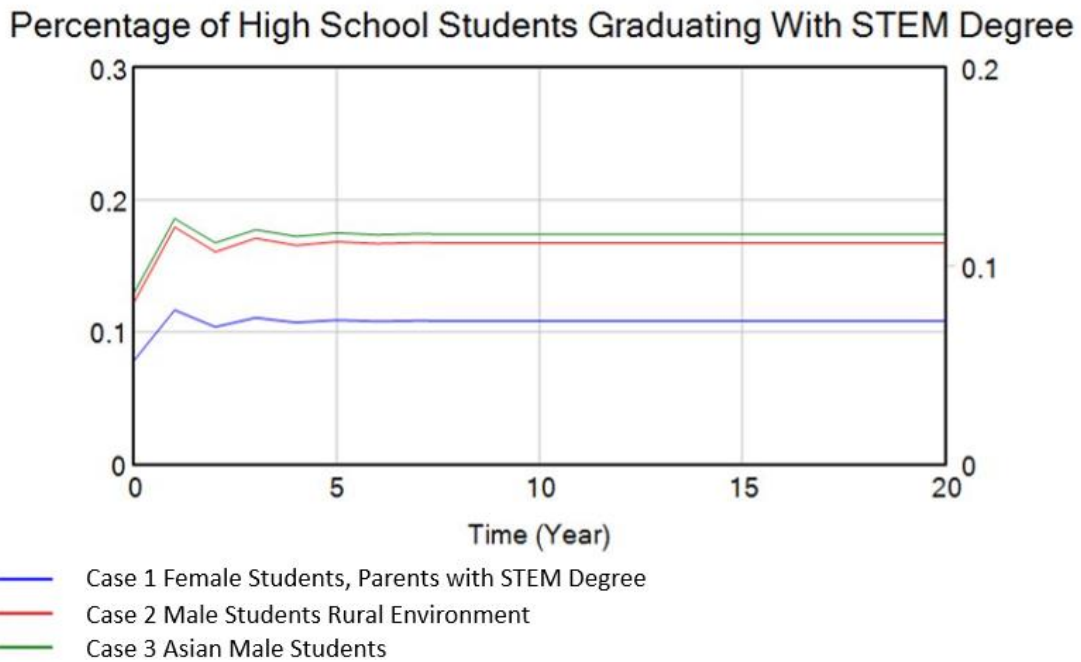


Figure 7f. Output of Model Simulations for Different Demographics

Policy changes are included in three areas of the model. The policy changes are shown in Fig. 7g. The first policy change alters the amount of average tuition, which determines the rate of high school students entering college. The second policy change models how increased STEM outreach can increase the percentage of college students entering STEM fields. The third policy change is the most complex policy and models the effects of tutoring and mental health resources on retention

rates. Increased resources have a positive impact on STEM retention; however, these resources may result in an increase in tuition, which negatively effects the number of college admissions. The system dynamics model provides an ideal way to model these complex policies to better understand the wide-spread effects different implementations could have throughout the system. The values used for the implementation of policy changes are purely for model demonstration purposes, and results of the current policy implementation are not tied to data at this point. However, when more data is acquired, accurate policy values can be determined, which will create more meaningful model results.

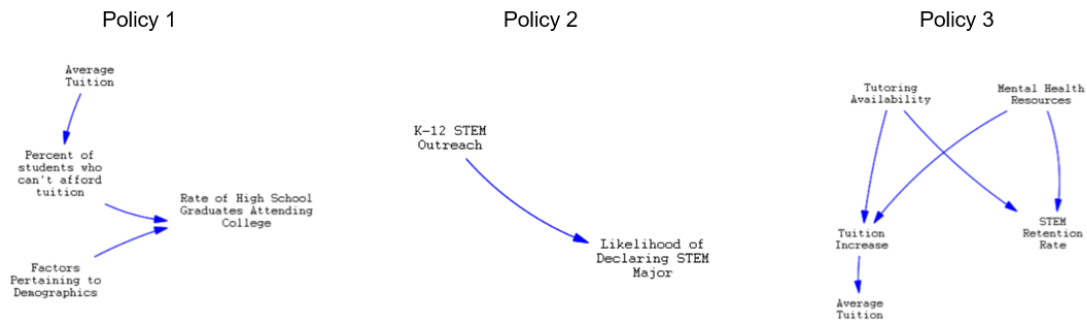


Figure 7g. Policy Changes Implemented to SD Model

Figures 7h and 7i show examples of the resulting values of policy changes made in year 11. Figure 7h shows the effect an increase of \$5,000 in tuition could have on the percentage of students graduating with a STEM degree. Figure 7i shows how an increase in K-12 outreach programs could positively affect the percentage of students earning STEM degrees. These plots demonstrate the System Dynamics model can be used to study and predict the effects policies could have on the complex system of higher education.

Percentage of High School Students Graduating With STEM Degree

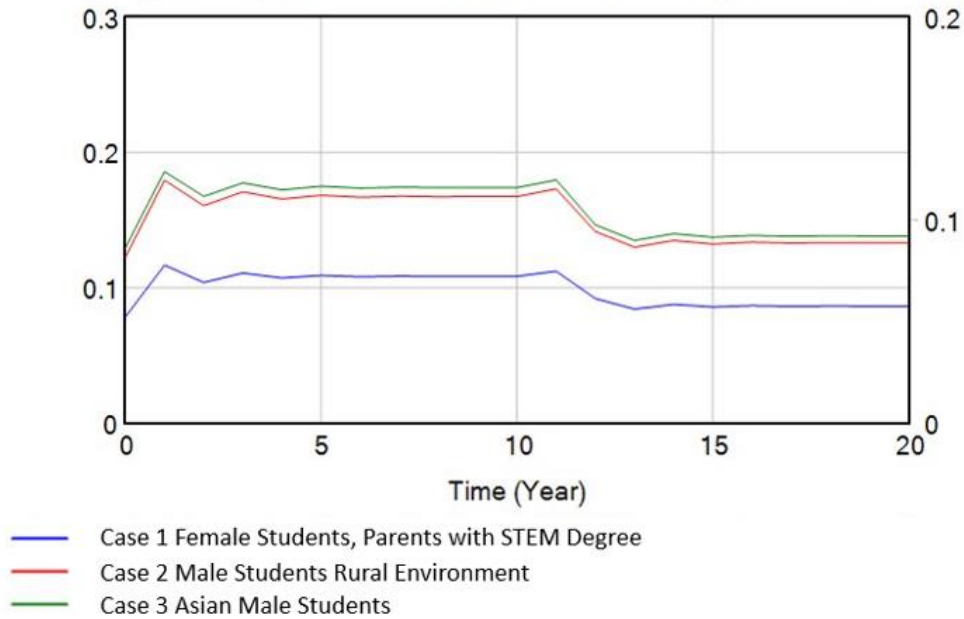


Figure 7h. Effect on Students Earning STEM Degrees After Tuition Increase of \$5,000 in Year 11 (Values for demonstration purposes only).

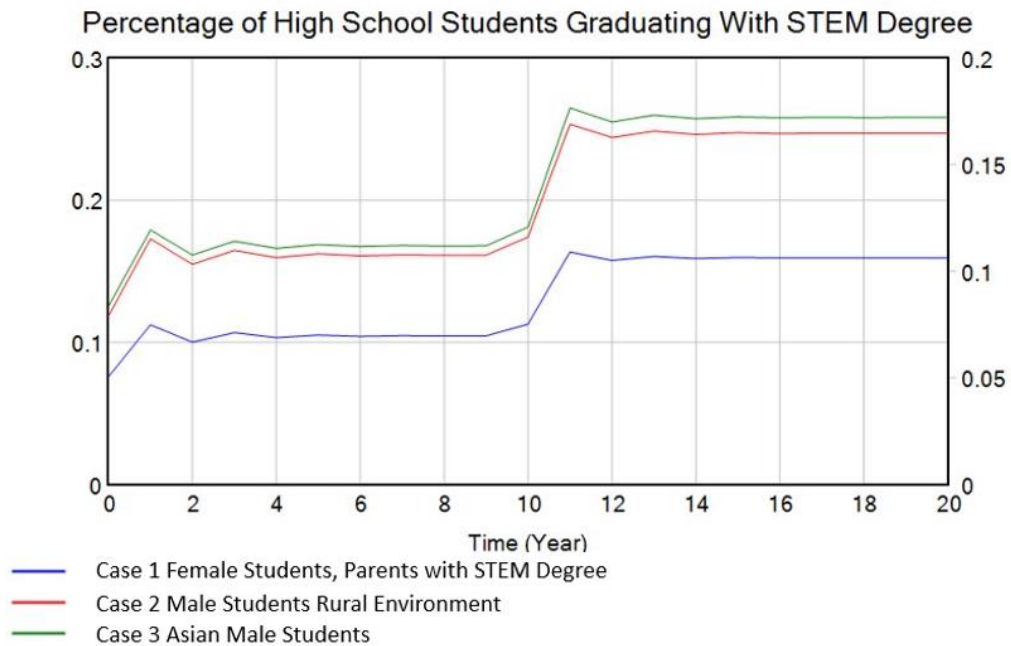


Figure 7i. Effect on Students Earning STEM Degree if K-12 STEM Outreach is Increased in Year 11 (Values for demonstration purposes only).

While the current policy change values are for demonstration purposes only, the current state of the model leaves ample opportunity to incorporate real data to generate more meaningful results. Future plans for this model also seek to incorporate more complex combinations of factors and possible interventions and examining the differing impacts on various demographics of students. Future work with the models may also address the differences in various types of schools or subgroups of students, depending on the availability of data.

Due to the limited empirical data available for the model and the complex non-linear dynamics associated with the data, methods using indirect inference may also be explored. These methods may provide reasonable parameter estimates using data simulated by the SD model.

ASSESSMENT OF SKILLED TECHNICAL WORKFORCE PROGRAMS IN FIVE STATES

Our nation has a strong and rewarding history that emphasizes the need for education and training to meet the workforce needs of business and industry. The federal government has been at the forefront for workforce development programs by enacting policy and providing funding enabling states to implement specific skilled workforce programs. The central goal among all the federal actions has been to address the skill gap between workers and the needs for business and industry.

There are six prominent federal Acts that have shaped workforce development in the United States.

- The New Deal (1933-1938)
- Manpower Development and Training Act (1962-1973)
- Comprehensive Employment and Training Act (1973-1982)
- Job Training Partnership Act (1982-1998)
- Workforce Investment Act (1998-2014)
- Workforce Innovation and Opportunity Act (2014-present)

The Workforce Innovation and Opportunity Act (WIOA) is significant because it required states to move beyond silo agency thinking into a more focused intentional strategy to meet the specific workforce needs of business and industry (B&I) located in their state. One of the important benefits from WIOA is a workforce economic solution that creates a partnership between federal and state government for funding and expertise, business and industry, and education providers to train for specific skills and competencies to meet B & I workforce needs and employers and economic development to hire and potentially recruit new industry to the state.

The WIOA requires all participating states to establish performance accountability indicators and performance reporting requirements to assess the effectiveness of State and local areas in achieving positive outcomes for individuals served by the workforce development system. At a minimum the performance standards include: 1) employment rate 2nd and 4th quarter after program exit; 2) type of credential attainment; and 3) measurable skill gains including competencies, on the job training and licensure.

We engaged five states -- Connecticut, Indiana, Michigan, Pennsylvania, South Carolina – to determine their efforts to develop a skilled technical workforce. All five are participating in the federal Workforce Innovation and Opportunity program. For the better part of the past year, we focused on meeting with key state representatives responsible for workforce development programs. There is recognition that a skilled workforce is needed to manufacture, operate, maintain and, in general, service these complex systems designed by computer scientists and engineers.

Leadership at the five-states overwhelmingly indicate that developing a skilled technical workforce is a very high priority for the governor and legislators. Also of importance, state leadership, in discussions with business & industry, has determined most entry level jobs in construction, information technology, transportation/logistics and manufacturing can be filled by a candidate with a high school diploma, short-term community college certificate, and on-the-job training.

From discussions with the five-state representatives there are three significant findings relative to skilled technical workforce programs:

- Because workforce demand and supply are specific to specific business and industry requirements, the potential employers must clearly define the types of jobs by classification, skills competencies required, number needed both currently and, in the future, and the level of experience needed whether entry level, mid-level, or above. At the same, time education providers must be forthcoming in describing their capacity to produce the training needed to deliver a workforce that meets business and industry expectations and needs.
- Skilled technical workforce training programs are expensive. Although states provide different models of workforce development programs funded through federal, state, and private partnerships, successful workforce programs require a consistent and reliable source of funds to support the training, equipment, and technology. These elements must ensure that students will train and use equipment and technology equivalent to what will be required once they are employed.
- It is imperative to develop appropriate program metrics for state government investment and ROI, likewise performance and outcome metrics need to be designed for business & industry, education providers, and students including indicators of student mobility. Program outcomes, such as changes in the knowledge and skills of current or future workforce participants, and access to

jobs or job opportunities that occur because of additional training and formal education, must be included.

This sample of state-based workforce programs indicates that every state is likely to recognize the importance of supporting and attempting to coordinate programs that will provide the essential workforce for the development of state based economic prosperity. Most state programs we have reviewed focus on the specific needs of the industries in their state, and each state has different methods of funding workforce development programs. Some state programs are coordinated and funded at the state level while others are more regional in focus.

While all states recognize the importance of data in the further development of these workforce programs, many challenges inhibit the creation of reliable outcomes measures to assess the impact of workforce development programs. Moreover, each state has its own priorities that are reflected in the data collected, inhibiting much cross-state comparisons. Finally, the stability of the funding for workforce development programs sponsored by state agencies varies with the priorities of governors and legislators.

We expect that an essential element of the workforce development model is the effort expended by various industries and industry groups through company specific workforce development programs that serve their direct needs. These programs are likely to be specific relative to the needs of individual companies and industries, and while they are likely to include good data on results and expenses, this data may not be available to outside review. The intentions and progress of these five states is summarized in Table 1.

Table 1. Comparison of Skilled Technical Workforce Training Across Five States

Program Attributes	Connecticut	Indiana	Michigan	Pennsylvania	South Carolina
Established a collaborative ecosystem that defines the roles and responsibility for state government, business & industry, education providers and economic agencies that clarifies roles as they collaborate on skilled technical workforce programs.	Established	In Progress	Established	Established	Established
Established a strategic focus for skilled technical workforce programs.	Established	In Progress	Established	In Progress	Established
Established the critical relationship between business & industry and education providers.	Established	In Progress	Established	In Progress	Established
Established a consistent funding model to leverage federal and state assets for skilled technical workforce programs.	Established	In Progress	In Progress	In Progress	In Progress

Established a target workforce: high school and community college students and skilled technical workforce programs.	Established	In Progress	In Progress	In Progress	In Progress
Established skilled technical training evaluation measures.	In Progress	Established	In Progress	In Progress	In Progress

IDENTIFICATION AND SUPPORT OF SELECTED UNIVERSITIES

We were interested in the extent to which findings differ by institution. Figure 8 shows the number of degree completions versus the percent STEM completions. There is a positive correlation between institutions that produce more degree completions and the percentage of those degrees that are in a STEM field, but the relationship is not particularly strong with 15% of the variance in degree completions explained by the percentage STEM.

This may reflect the possibility that larger STEM student bodies correlate with higher quality student bodies in general.

The circles in Figure 8 designate the three-year average DoD sponsored research expenditures. A few institutions dominate this metric, making it very difficult to generalize from this data. There is no strong relationship between the number degrees awarded and the DoD sponsored research expenditures.

Policies intended to enhance the STEM talent pipeline are not likely to affect all educational institutions equally. Consequently, the attractiveness of incentives, for example, may differ across institutions, prompting varying responses. Our applications of EMRU to in-depth studies of several major research universities, showed that resource characteristics of a university – endowment, sponsored research, etc. – can enable or constrain how they can best respond to strategic challenges.

The application of EMRI to Georgia Southern, Northern Illinois, University of Colorado at Denver, University of Texas at Arlington and University of Texas at Rio Grande showed that number of students, retention percentages, and financial situation affects the economics of supporting students and enhancing pedagogical processes. One size may fit all in general, but not in particular.

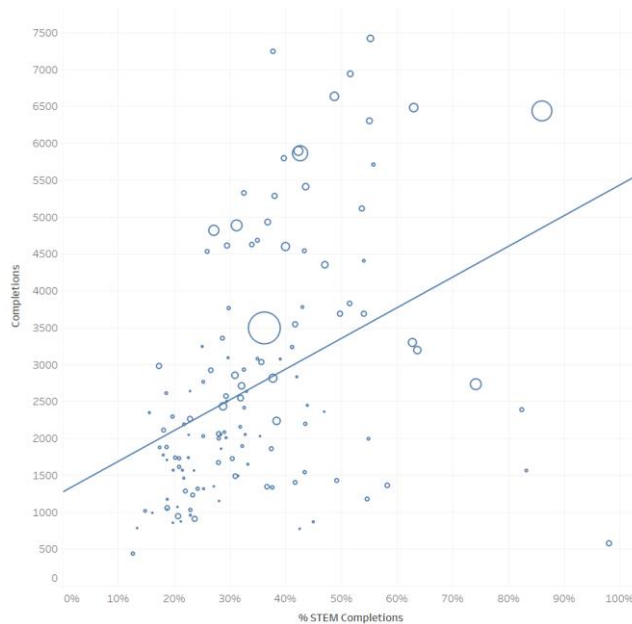


Figure 8. Percent Overall Degree Completions Versus STEM Completions

Application of EMWI to our ongoing investigations of workforce development on CT, IN, MI, PA and SC suggests that sources of funds, organizational structure, and other factors likely affect the economic results. Data gathering and accessibility affect abilities to attribute costs, capture outcomes, and learn from ongoing operations.

ENGAGING AND NURTURING PROMISING HIGH SCHOOL STUDENTS

We devoted considerable time this year to assessing the nature of K-12 education across the US in terms of STEM offerings, but also the availability of STEM camps, internships, and other experiences. We also gained insights, trends, and regression models from the HSLs datasets discussed earlier.

In general, K-12 education in the US varies widely, in part due to 14,000 independent school boards that manage K-12. The best schools are quite impressive. The poorest schools border on appalling. It is not within the purview of the federal government to “fix” this problem.

Not only do schools differ, students’ readiness, preparation, and aspirations differ significantly. As represented in the Behavioral Economics Model of Student Choice in Figure 4, a variety of factors affect a student’s choice of institution, STEM majors in general, and specific disciplines in particular. Several behavioral factors underlie these choices. Employment choices are also impacted.

We recommend that ongoing efforts for this task focus on interventions to directly support students rather than educational institutions. There has been a wide variety of pilot studies focused on enhancing students’ readiness, preparation, and

aspirations. The implications of scaling these interventions should be considered. At the very least, we should be able to project the implications if these interventions were scaled.

MODELING IMPACTS OF POLICY INSTRUMENTS ON STEM TALENT PIPELINE

This project thus far has approached the issues in two somewhat distinct ways. The economics models -- EMRU, EMRI, EMWI and BEMSC – are based on core economic principles, including time series projections, discounted cash flows, and utility theory. The goal is to project the economic impacts of investment policies. These models have been tailored to a range of institutions and organizations.

The system dynamics modeling, both the general and specific versions, has focused on the causal dynamics of how students select STEM majors, matriculate and progress, and graduate to move into the workforce. This is addressed in general, for higher education broadly, and will be addressed specifically for one institution – Purdue University – in the coming year.

The two approaches are intended to support each other, as is outlined below during the discussion of the possibility of an integrated model.

GRAPHICAL PORTRAYAL OF STEM TALENT PIPELINE

All of the model development efforts began by mapping the STEM talent pipeline. Figures 9a and 9b provide a graphical portrayal of this pipeline. Figure 9a portrays the flow from high school through post-secondary education to employment. Figure 9b portrays the flow through K-12. Both figures include indications of transition probabilities between stages of the overall process of education.

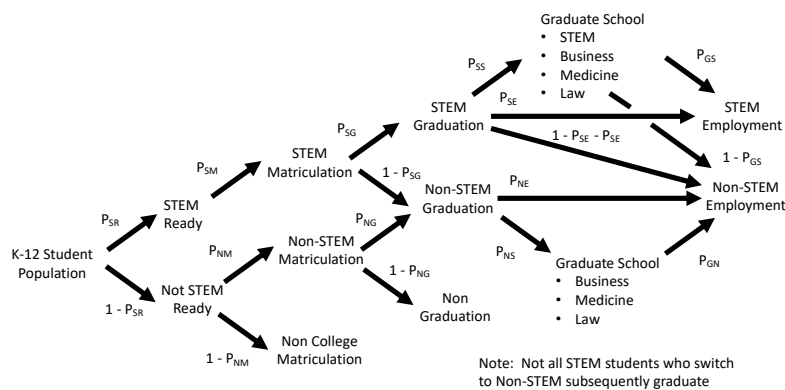


Figure 9a. Overall Talent Pipeline Model

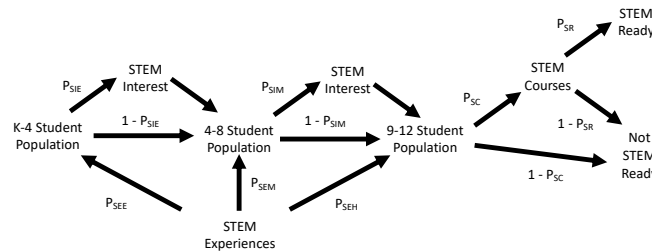


Figure 9b. Elementary & Secondary Schools Pipeline

Table 2 summarizes the 17 transition probabilities in Figures 9a and 9b. Rough estimates of several of these transition probabilities from the literature include:

- 16% of HS grads are STEM ready
- 20+% of HS grads choose STEM majors
- 50% of STEM students graduate non-STEM
- 60% of STEM grads take non-STEM jobs
- 90% of STEM grads use STEM skills in jobs

Better evidence-based estimates are needed for all of the probabilities in Table 2. This poses an enormous challenge as these probabilities quite likely depend on particular schools, student gender and race, parental education and income, and many other factors. The lack of availability of curated, standardized data greatly complicates this challenge. The sources of the above estimates are summarized in Appendix E.

Table 3 considers the policy interventions that could affect the transition probabilities in Table 2. Clearly, there is a wide range of possible policy interventions. There is very limited data on the costs and effectiveness on most of these interventions. Unlike medicine, the education domain does not include the equivalent of randomized clinical trials. Perhaps the health and education domains most overlap in terms of prevention and wellness, where the phenomena of interest are broadly defined and distant in time.

Table 2. Parameters of Pipeline Model

	Elementary & Secondary Schools		Post-Secondary School
PSIE	Prob STEM interest in elementary school	PSM	Probability STEM matriculation
PSEE	Prob STEM experience in elementary school	PNM	Probability Non-STEM matriculation
PSIM	Prob STEM interest in middle school	PSG	Probability STEM graduation
PSEM	Prob STEM experience in middle school	PNG	Probability Non-STEM graduation
PSEH	Prob STEM experience in high school	PSS	Probability STEM to graduate school
PSC	Prob STEM courses in high school	PSE	Probability STEM to STEM employment
PSR	Prob STEM ready	PNS	Probability Non-STEM to graduate school
		PNE	Probability Non-STEM to employment
		PGS	Probability graduate school to STEM employment
		PGN	Probability graduate school to Non-STEM employment

Table 3. Impacts of Policy Interventions

Policies	Impacts of Policies
Incentives to provide offerings that increase students' interest and competencies.	Increase PSIE, PSIM, PSC
Incentives to provide STEM experiences to increase interest and competencies.	Increase PSEE, PSIE, PSEM, PSIM, PSEH
Incentives for industry to provide paid internships	Increase PSEH, PSC, PSR
Information that enhances students' abilities to make well-informed decisions	Increase PSM
Incentives to provide accessible offerings at community colleges and universities.	Increase PSM, PSG
Incentives for vocationally oriented offerings.	Increase PSM, PSH, PSE
Incentives to provide knowledgeable and skilled counseling and coaching.	Increase PSG, PNG
Scholarships to foster knowledgeable, skilled, and motivated STEM professionals	Increase PSR, PSM, PSG, PSS, PSE
Incentives to encourage employee involvement in STEM professional societies	Increase PSE, PSS
Incentives to participate in regional alumni associations	Increase PSE, PSS
Information to support identifying and pursuing STEM employment opportunities.	Increase PSE, PSS

INTEGRATED MODEL OF STEM TALENT PIPELINE

The second year will focus on modeling the impacts of policy instruments on the STEM talent pipeline. A variety of models have been discussed throughout this report. How might all of these component models come together to create an integrated model of the STEM talent pipeline? This section considers how such integration might be accomplished.

Figure 10 portrays a notional integrated model. The policy levers and desirable predictions are starting points. The first step in the model integration process involves specifying the eventual users of the integrated model and their preferences for policy levers and predictions. These preferences will guide determination of the underlying elements to be considered in providing a model-based mapping from levers to predictions.

The flow model portion of Figure 10 provides a very high-level view of how populations of K-12 students transition into students at community and four-year colleges, and subsequently transition into employment. The arrows in Figure 10 represent transformations of time series, for example, of K-12 students into college students.

If users' concerns were limited to "What is?" these time series might be identified from a range of data sets, some of which were discussed earlier. This could enable assessing the extent to which policy levers of interest had affected metrics of

interest. Identifying and assessing the requisite data might be a challenge, but in principle, at least, this is straightforward.

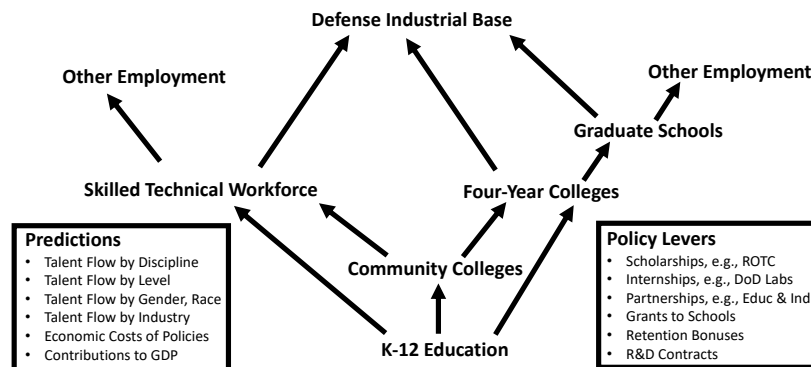


Figure 10. Notional Integrated STEM Talent Pipeline

It is likely that users' concerns would include "What if?" questions. Answering these types of questions can be informed by empirical data on current operations, but these questions often cannot be answered using such data, unless one is willing to assume that the future will be a linear extrapolation of the past.

If this assumption is not warranted, then mathematical models are needed to represent the transformation on one time series into another. These models might be derived from first principles of economics, psychology, etc. Alternatively, one or more standard representations might be adopted including:

- **Systems Dynamics** to represent the interactions of causal feedback loops
- **Discrete Event** to represent flows and queues of students
- **Agent-Based** to represent individual decision making by students

We have made significant progress on a system dynamics model of student flows into STEM majors, retention, and graduation. In the second year, we can explore extensions and refinements to the model. These include incorporating more factors and flows as more data becomes available, and tailoring the model to distill the impact of policy interventions on different archetype groups (e.g., urban female vs. rural male). We can also apply robust scientific methods to verify and validate the systems dynamics model. For example, the indirect inference method can be used to estimate and refine the system dynamics model parameters by leveraging data simulated by the model.

Representing the economics of education will require dovetailing two representations, for example, with time series from the system dynamics model serving as inputs to economic models such as discussed earlier. The full range of representations needed, and how these representations are integrated, depends

totally on users' preferences for policy levers and predictions of interest. Models are intended to answer questions. Thus, the next step is to fully delineate these questions.

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APPENDIX A: ECONOMIC MODEL OF RESEARCH UNIVERSITIES

Figure A1 show the input parameters used to compute a university's economic future.

Model Settings (Per Year)	
Number of Colleges	8
Number of Depts/College	6
Number of Undergraduates	16,000
Undergrad Growth Rate	0.01
Undergrad Tuition (Net)	15,000
Undergrad Tuition Growth Rate	0.03
Number of Graduate Students	5,000
Grad Growth Rate	0.04
Grad Tuition (Net)	24,000
Grad Tuition Growth Rate	0.05
State Funding (Per Year)	100,000,000
State Funding Growth Rate	0.02
Endowment	600,000,000
Endowment Growth Rate	0.065
Endowment Earnings Rate	0.05
Percent Tenure Track Faculty	0.3
Overhead Rate (Non Admin)	0.5
NPV of Surplus/Deficit	3,221,042

Figure A1. Input Portion of EMRU Dashboard

Figure A2 illustrates projections of student enrollment and costs per student. Figure A3 shows projected revenue, costs and net surplus/deficit. Figure A4 depicts projected brand value for the university. The projections in Figures A2-A4 reflect the choices made on the dashboard of Figure A1. These projections are computed utilizing the underlying economic model of the particular university of interest.

Figure A5 portrays the overall flow of variables within the economic model. Not every connection is portrayed, as the figure would become hopelessly messy. Of particular note, students' applications and enrollments are driven by a tradeoff between net tuition and brand value. Somewhat simplistically, students seek to matriculate at the highest brand value university that they can afford.

Figure A6 shows how all the models come together, with the variables within each model listed. The financial model that follows Figure A5 is not shown in Figure A6 as it draws revenue and cost data from all the other models. Showing all these linkages would also make this figure quite messy.

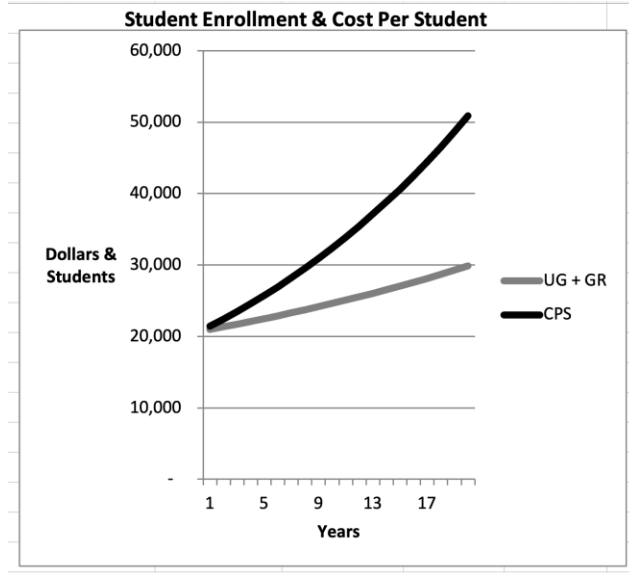


Figure A2. Projected Student Enrollment and Cost Per Student

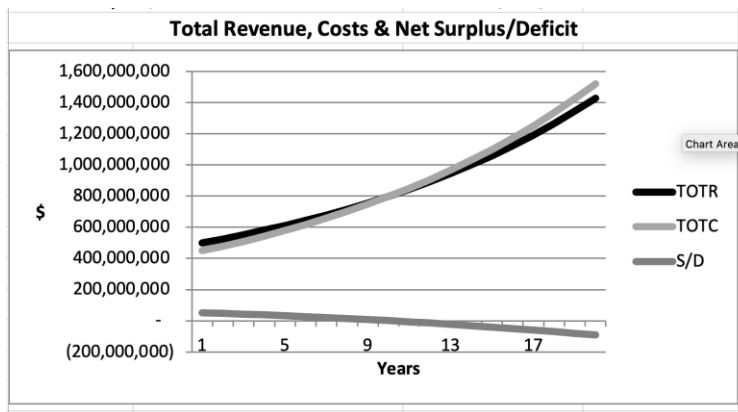


Figure A3. Projected Revenue, Costs & Net Surplus/Deficit

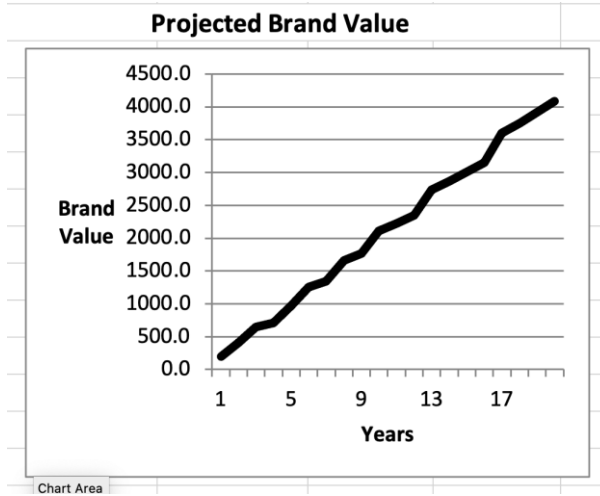


Figure A4. Projected Brand Value

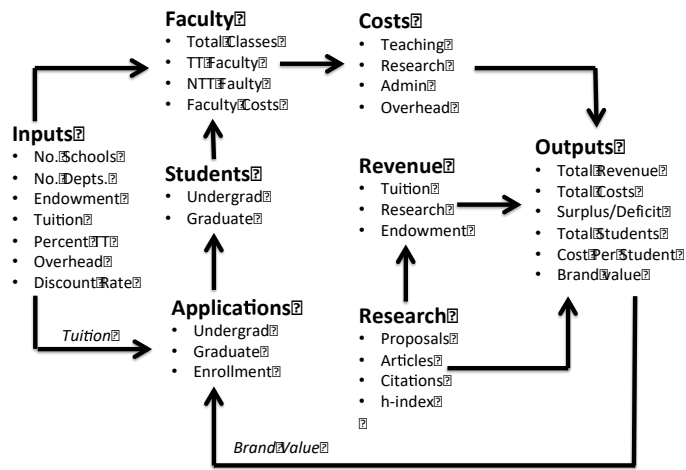


Figure A5. Overall Structure of Economic Model of Academic Enterprises

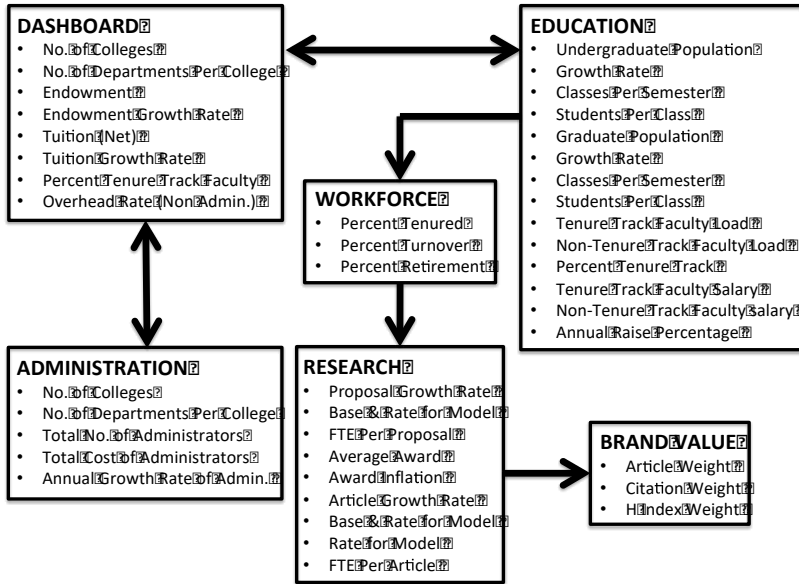


Figure A6. Computational Modules and Variables

The variables listed in Figure A6 are elaborated in Table A1. The variables included on the Dashboard are those that are usually varied to address “What if” questions. The input variables included within individual models can be tailored to particular institutions, but are not usually varied. Of course, any of these variables could be moved to the Dashboard. Note that three variables are computed and eight variables are based on empirical data.

Table A1. Variables Within Overall Model

Dashboard		Base for Model	Data
Number of Colleges	Input	Rate for Model	Data
Number of Departments/College	Input	FTE Per Article	Input
Endowment	Input	Education	
Endowment Growth Rate	Input	Undergraduate Population	Input
Tuition (Net)	Input	Growth Rate	Input
Tuition Growth Rate	Input	Classes Per Semester	Input
Percent Tenure Track Faculty	Input	Students Per Class	Input
Overhead Rate (Non Admin)	Input	Graduate Population	Input
NPV of Surplus/Deficit	Computed	Growth Rate	Input
Finance		Classes Per Semester	Input
Discount Rate	Input	Students Per Class	Input
Admin		Faculty	
Number of Colleges	Dashboard	Tenure Track Faculty Teaching Load	Input
Number of Departments Per College	Dashboard	Non-Tenure Track Faculty Teaching Load	Input
Total Number of Administrators	Computed	Percent Tenure Track	Dashboard
Total Cost of Administrators	Computed	Tenure Track Faculty Salary	Input
Annual Growth Rate of Admin	Input	Non-Tenure Track Faculty	Input
Proposals		Annual Raise Percentage	Input
Proposal Growth Rate	Data	Workforce	
Base for Model	Data	Percent Tenured	Input
Rate for Model	Data	Percent Turnover	Input
FTE Per Proposal	Input	Percent Retirement	Input
Average Award	Input	Brand Value	
Award Inflation	Input	Article Weight	Input
Articles		Citation Weight	Input
Article Growth Rate	Data	H Index Weight	Input

APPENDIX B: ECONOMIC MODEL OF RETENTION INVESTMENTS

EMRI Dashboard

Figure B1 show the dashboard for the Economic Model of Retention Investments. The input variable are defined below. This highlighted in green are input on the dashboard. This highlighted in yellow are computed elsewhere in the model.

Dashboard			
Economic Model of Retention Investments			
N	1,000	Number of students at risk of attrition	
PH	25%	Percent students at high risk	
PM	50%	Percent students at moderate risk	
PL	25%	Percent students at low risk	
\$W	7,000	Tuition per student per semester (beyond cost of instruction)	
\$X	3,990	Support costs per student per semester (From Support \$)	
\$Y	460,000	Process costs for each of four semesters (From Process \$)	
\$Z	1,000	Bonus for risk reduction per student per semester	
Alpha	0.30	Success rate per semester (0.1 - 0.9)	
DR	3%	Discount rate for NPV calculation	
Expected Value (0.50) Model		NPV	\$27,499,150
Number of Students Retained		NSR	681 91%
Total Retention Bonuses		TRB	\$680,822
Confidence Level (0.95) Model		NPV	\$27,025,214
Number of Students Retained		NSR	145 19%
Total Retention Bonuses		TRB	\$145,000

Figure B1. Dashboard for Economic Model of Retention Investments

User of EMRI

The Economic Model of Retention Investments (EMRI) is intended to support strategic thinking about investments in retaining college students in their chosen academic majors. This is a substantial challenge, as the Findings tab in EMRI summarizes. Institutions have three ways to improve retention:

1. Attract better prepared students
2. Provide support to poorly-prepared students
3. Improve pedagogical processes to overcome bottlenecks

EMRI can help to understand the tradeoffs among these approaches, as well as create combinations. The nature and costs of student support can be tailored to specific institutions via the Support \$ tab. The nature and costs or process improvement can be tailored to specific institutions via the Process \$ tab.

Inputs on the Dashboard include per semester tuition beyond the costs of instruction. The variable revenue due retention of high-risk students can be varied to see what it would take to make this whole process financially viable. The source of such "bonuses" might be federal or state grants, philanthropic funds, or other sources. The discount rate, DR, reflect particular institutions financial practices.

Alpha, the success rate of supports and improvements, ranging from 0.1 to 0.9, might be based on past experiences with such investments. We have found little data upon which to base estimates of Alpha. An initial approach might be to vary Alpha to determine what levels are needed to make these investments financially viable. Of course, as experience is gained for any particular institution, estimates of Alpha will emerge.

Decreasing the costs of support and process improvements can also increase financial viability. There are increasingly effective opportunities to use technology to decrease these costs, particularly per student. The benefits of these possibilities can be incorporated in your institution-specific formulations of the Support \$ and Process \$ tabs.

Note that both the expected value of the Net Present Value (NPV) and the 95% confidence level are calculated. The expected value is such that 50% of the time actual results will be higher and 50% of the time results will be lower. The 95% confidence level is such that 95% of the time actual results will be higher.

EMRI Inputs

N is the number of students at risk of attrition

PH is the percent students at high risk

PM is the percent students at moderate risk

PL is the percent students at low risk

\$W is the tuition revenue per student per semester beyond cost of instruction

\$X is the variable cost of student support services

\$Y is the fixed cost of process improvements

\$Z is the variable revenue due to retention of high-risk students

Alpha is the success rate of supports & improvements (0.1 - 0.9)

DR is the discount rate for NPV calculation

EMRI Outputs

NPV (0.50) is the expected value of the NPV

NPV (0.95) is the 95% confidence level of the NPV

NSR is the Number of Students Retained

TRB is the Total Retention Bonuses

NSR is calculated for both the expected value and the 95% confidence level of the NPV

TRB is calculated for both the expected value and the 95% confidence level of the NPV

Sensitivity of Outputs to Inputs

Increasing N increases both tuition revenue and variable costs

Increasing N spreads fixed costs across more students

Increasing Alpha moves more students from high-risk to low-risk

Increasing DR discounts downstream returns on investments

APPENDIX C: ECONOMIC MODEL OF WORKFORCE INVESTMENTS

Figure C1 shows the dashboard for this model.

Economic Model of STW Investments	
Investment	1,000,000 Amortized over N years
Operating Costs	5,000 Per student per year
Depreciation N	10
Depreciation	100000 Investment/years
No. STW Student:	100
Job Multiplier	1.7 NTW jobs created per STW
Income STW	50,000 Per STW employee per year
Income NTW	30,000 Per NTW employee per year
Consumption	0.8 Percent of income consumed
Taxes	0.2 Percent of income for federal, state, and local taxes

Figure C1. Dashboard of Economic Model o Workforce Investments

Over the time period of interest, the model predicts:

- Cumulative size if skilled technical workforce (STW)
- Cumulative size of the non-technical workforce (NTW)
- Cumulative STW per hundred
- Cumulative Costs/Tax Revenues
- Income of STW per year
- Income of NTW per year
- Total Income per year
- Total Costs per year
- Tax Revenue per year
- Total Costs/Tax Revenue per year

An example projection is shown in Figure C2.

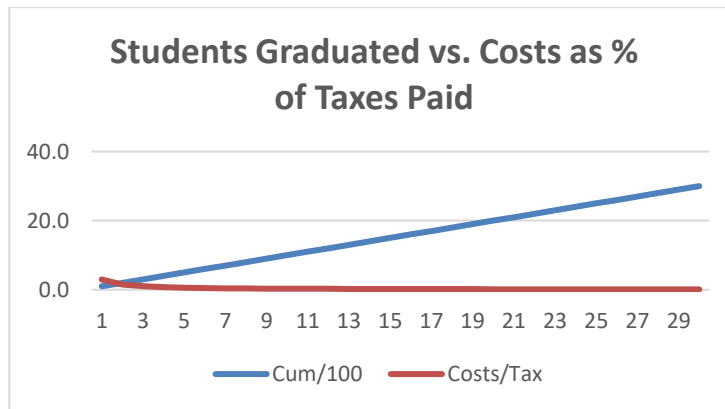


Figure C2. Cumulative Graduates (000s) and Costs as % of Taxes Paid (000s)

APPENDIX D: BEHAVIORAL ECONOMICS AND STUDENTS' DECISIONS

Should one go to college? Where to apply and where to enroll? What choice of major? What choice of employment? These types of decisions are faced by millions of students and graduates. They affect the flow of talent into our workforce and our competitive advantages – or disadvantages – relative to other players in the global marketplace. Do we understand the behavioral economics of these choices? This article explores these questions and suggests how answers to these questions can influence policy.

INTRODUCTION

Recent studies have focused on strategies that educational institutions could adopt to address a range of challenges (Rouse, 2016; Rouse, Lombardi & Craig, 2018). Our model-based conclusions have been that less well-resourced universities are going to struggle financially to deal with scenarios involving the increasing quality of educational technologies and decreasing foreign student enrollments in graduate programs. Indeed, the coronavirus pandemic has greatly accelerated these challenges.

Our current efforts are concerned with students' decisions as they interact with institutional decisions. In particular, we are addressing alternative policies to enhance the STEM workforce pipeline. By STEM we mean science, technology, engineering, and mathematics. Some organizations advocate adding an A for arts, hence STEAM, or M for medicine, hence STEMM. The merits of these changes depend on the population of interest, which is not addressed in this article.

This article proceeds as follows. We first consider the broad field of behavioral economics and summarize key findings. We then consider research findings on students' decisions regarding STEM. These findings are summarized in terms of a behavioral economics model of student decisions making. This model is employed to articulate alternative policies for enhancing the STEM talent pipeline. The feasibility and costs of these policies are discussed.

BEHAVIORAL ECONOMICS

Behavioral economics is concerned with the effects of psychological, cognitive, emotional, cultural and social factors on decision making by individuals, groups, organizations and institutions. The original emphasis was on and how these decisions varied from those posed by classical economic theories. Over more than four decades, a wealth of studies has been conducted and findings published.

The motivations for this research and the inventive ways employed to address research questions are wonderfully explained and illustrated in *Thinking, Fast and Slow* (Kahneman, 1994), *Nudge* (Thaler & Sunstein, 2009), and *Misbehaving* (Thaler, 2016). This article focuses on understanding the behavioral

economics of students' decisions. It is useful, however, to consider several overall findings in this field.

Table D1 summarizes ten general findings in term of descriptions of how people actually make decisions, rather the classical economic prescriptions for how people should make decisions. Example manifestations of how students make decisions are listed beside the behavioral economics phenomena. It is very easy to imagine these phenomena strongly affecting students' decisions.

Table D1. Behavioral Economics Phenomena & Students' Decisions

Behavioral Economics Phenomena	Manifestation in Students' Decisions
People tend to have fast immediate response & slow deliberative responses	Students' initial reactions to decisions may preempt more reflective decisions
People tend to ignore the base rate likelihood of uncertain events	Students tend to underestimate or overestimate probabilities of success
People tend to predict representative outcomes rather than expected values	Students predict probabilities of success that they have observed with others
People judge the likelihood of imaginable events as more likely	Students imagine success in career that they paths have observed
People have difficulty trading off near-term vs. long-term outcomes	Students are more concerned with this semester than the "futuraity" of decisions
People love discounts relative to their expectations	Student select courses that are "good deals" vs. work required and outcomes
People hate losing much more than they value winning	Students strongly dislike failing, much more so than succeeding
People bet on long-shots to hopefully, but not likely, make up for losses	Students will bet on long-shots to shore up poor GPA results
People tend to search for confirming rather than disconfirming evidence	Students are likely to seek confirming evidence from peers, not refutation
People are likely to poorly frame risk-reward tradeoffs, undermining decisions	Students have difficulty understanding returns of decisions and associated risks

It is important to note that many findings in behavioral economics are based on hypothetical decisions made by college students. Typical responses are highly influenced by the framing of questions, e.g., whether a student is deciding to buy vs sell something. The field has received criticism for these types of non-real-world experiments.

More recently, behavioral economics researchers have focused on “natural experiments” such as the National Football Team (NFL) owners deciding on picks in the NFL Draft or quiz show contestants’ decisions in high-stakes games. Thaler (2016) discusses such studies at length. This trend has ameliorated criticism.

FACTORS AFFECTING STUDENTS’ DECISIONS

The topic of how students choose college majors has received extensive study. It is much more complicated than might appear on the surface, involving interactions of the aspirations, aptitudes, and attitudes of students in middle school, high school, and early years of college. Relative to pursuing STEM (science, technology, engineering, and mathematics) majors, it is not a simple question of whether they liked and were proficient in high school mathematics.

There is an extensive literature on this topic. Table D2 provides a sampling. The issues range from the institutions where students seek admission, to what academic majors they choose to pursue, to what motivates STEM majors, to what behavioral and social phenomena motivates particular choices. This article addresses this range of perspectives.

Table D2. Factors Associated with Students Choices

Topic Addressed	Source
Factors affecting choice of institution	Hoyt & Brown (2003)
	Mattern and Wyatt (2009)
	Stark & Scholder (2011)
	Noel-Levitz (2012)
Factors affecting choice of majors	Trusty (2002)
	Malgwi, Hover, & Burnaby (2005)
	Williams (2007)
	Maltese (2008)
	Mattern, Shaw, & Ewing (2011)
	Fizer (2013)
	SalahJaradat (2015)
	Haggag, Patterson, Pope, & Feudo (2019)
	Darolia, R., Koedel, C., Main, J.B., Ndashimye, J.F., & Yan, J. (2020)
	Wyatt, Feng and Ewing (2020)
Tan, Main & Darolia (2021)	
Factors affecting choice of STEM majors	Wang (2013)
	Phelps, Camburn & Min (2018)
	Zahorian, Elmore, & Temkin, (2013)
Behavioral skills, barriers & interventions	Koch, Nofziger, & Nielson (2015)
	Lavecchia, Liu, & Oreopoulos (2015)

Factors Affecting Choice of Institution

A university's brand value plays an important role in several phenomena. It affects students' choices of where to apply and, if accepted, enroll. Many factors affect students' choices, but brand value and costs dominate (Hoyt & Brown, 2003; Noel-Levitz, 2012).

Mattern and Wyatt (2009) studied student choices of college in terms of how far students go for an education. Using a sample of 1 million students, they found that the distance students travel varies by state, SAT score, high school GPA, parental income, parental education, ethnicity, and gender. Distance traveled increased with parental income, parental education, and academic preparation. The first two of these factors are likely to influence the third.

Stark and Scholder (2011) present a methodological approach comparing "stated" versus "derived" importance – what students said versus what they actually did. They find that derived performance better predicts choices, often including factors students indicated did not greatly matter.

Three of these reports are from consultants engaged with supporting university enrollment management functions, which have become increasingly sophisticated, although a bit derailed by the pandemic. Their statistical models are useful for predicting how many students will enroll; less so for which students will enroll.

Factors Affecting Choice of Majors

Several articles report findings on factors that affect college majors chosen, across all majors, not just STEM.

Trusty (2002) studied the role of course taking-behavior in high school on subsequent college major and found that taking rigorous math and science courses (Algebra I & II, Geometry, Chemistry, Biology and Physics) is related to an increased likelihood of majoring in a STEM-related field.

Malgwi, Hover, and Burnaby (2005) report on 3,800 students in a northeast business school. Factors affecting choice of major include interest in the subject, aptitude for the subject (women), and potential for career advancement and compensation (men). Changes of major were due to positive factors associated with the new major, rather than negative factors associated with the old major.

Williams (2007) reports on students' characteristics and external influences affecting choices of majors. Student characteristics include personal associations in major, level of professional aspirations, aptitude, and high school experiences. External influences include significant persons (family & friends, high school personnel, and professionals in the field), exposure to the major (publications, family associations, and personal experiences) and college factors (recruitment, personal contact, and reputation).

Maltese (2008) studied the role of course taking-behavior in high school on subsequent college major and found that taking rigorous math and science courses (Algebra I & II, Geometry, Chemistry, Biology and Physics) is related to an increased likelihood of majoring in a STEM-related field.

Mattern, Shaw and Ewing (2011) investigated the relationship between Advanced Placement (AP) participation and performance with choice of college major. They examined whether students who take an AP Exam in a particular domain are more likely to major in that domain than students who did not take this AP exam. Results reveal a positive relationship between AP participation and majoring in a related field in college. The effect was stronger for AP exam in computer science and majoring in computer science in college, compared to AP exams in humanities or social sciences.

SalahJaradat (2015) performed a multi-dimensional analysis of undergraduate choices of major in a private university. Correlations with college reputation, teachers, school advisor, job opportunities, interest in the subject, and aptitude were all in the 0.1-0.2 range. This suggests that, at least for this population, no one or two factors dominated.

Fizer (2013) reported on factors affecting choice of academic majors in agriculture. The most frequently reported factors were family (22%), a career that is personally rewarding (21%), experience with Future Farmers of America and 4-H (20%). Of course, these students had already chosen to pursue careers in agriculture, just not their majors.

Haggag, Patterson, Pope, and Feudo (2019) found that student choices of majors at West Point were affected by rather subtle factors. Assignments to early morning sections of general education subjects resulted in 10% decreases in the likelihood of choosing to major in that subject. Fatigue from back-to-back courses prior to a general education subject resulted in decreases in the likelihood of choosing to major in that subject.

Darolia and colleagues (2020) provide a rigorous statistical analysis on data for 140,000 students entering the four-year public university system in Missouri. They found that differential access to high school math and science courses did not affect postsecondary STEM enrollment or degree attainment. They caution that this does not imply that advanced courses should be eliminated.

Wyatt, Feng and Ewing (2020) found that the AP Computer Science Principles (CSP) course attracts more diverse students than AP Computer Science A (CSA), with a greater proportion of female, Hispanic, Black, and first-generation students taking CSP than CSA. Their analyses demonstrate that CSP participation is positively associated with students' college major choice, with CSP students three times more likely to declare a computer science major at the start of their first year in college, and also more likely to declare STEM majors. These differences are even larger for female and Hispanic students.

Tan, Main, and Darolia (2021) using data from the High School Longitudinal Study of 2009, employed the random forest method, a genre of machine learning, to rank the most important high school-level factors in terms of predictive power of engineering major choice. They found that student gender is the most important variable predicting engineering major choice, followed by high school math achievement and student beliefs and interests in math and science during high school.

These findings are all relatively consistent, although at differing levels of resolution. Clearly more factors are involved than interest in the subject and aptitude for the subject. There are significant social factors that influence students' choices.

Factors Affecting Choice of STEM Majors

Wang (2013) reports on factors affecting choices of STEM majors. Not surprisingly, intentions to major in STEM play a significant role. Exposure to math and science courses, as well as high school math achievement play roles. Math self-efficacy beliefs are also important. Initial post-secondary experiences can reinforce STEM choices. Finally, receipt of financial aid plays an obvious role.

Phelps, Camburn and Min (2018) report that academic preparation and orientation is a strong predictor of choosing STEM majors. Students who take pre-college engineering courses have a 60% increase in likelihood of STEM enrollment. Early relevant post-secondary experiences also increase this likelihood.

Zahorian, Elmore and Temkin (2013) discuss the choices of majors by 300 engineering freshmen. Three factors were rated by students as most important in their major selection process: personal academic interests, potential for societal contributions, and job prospects. Of course, these students had already chosen to pursue careers in engineering, just not their majors.

Clearly, the likelihood of pursuing STEM in general, or engineering in particular, is greatly enhanced by high school experiences such as pre-college engineering courses, as well as early relevant post-secondary experiences. The first author remembers his experiences working in his uncle's plumbing company and how installing and maintaining various plumbing systems greatly increased his interest in mechanical engineering so he could really understand how and why these systems functioned.

Behavioral Factors Affecting Choices

Koch, Nofziger and Nielson (2015) argue for looking beyond cognitive skills as measured by achievement tests. They report that soft skills are also important to academic success. These soft skills include self-control, willingness to compete, intrinsic motivation, and self-confidence. They suggest that educational investments should consider how both cognitive and soft skills will be engendered.

Lavecchia, Liu and Oreopoulos (2015) provide a very impressive and comprehensive review of literature on behavioral barriers to academic success and interventions to overcome these barriers. Behavioral barriers include students focusing too much on the present and relying too much on the routines of education. These barriers impede students' inclinations to consider their futures. Some students focus too much on avoiding negative identities rather than deeper aspects of alternative futures. Overall, students are more likely to make poor choices with many options or little information.

The authors provide a very useful compilation of interventions proven to help overcome behavioral barriers, with research literature cited for each suggestion. Five in-depth tables include:

- Interventions that aim to offset immediate costs with immediate benefits
- Interventions to help reduce inertia and change routine for students
- Interventions to help reduce inertia and change routine for parents
- Interventions to help reduce inertia and change routine by changing defaults and adding structure
- Interventions that strengthen positive identities

Clearly, these findings from behavioral economics argue for addressing the whole student, both to enable success in general as well as to support STEM aspirations where warranted. Interestingly, this finding is very similar to the need to address the whole patient discussed in health and wellness publications.

Overall Findings

Table D3 provides an overall, qualitative summary of the findings of this case study. The primary consideration change as students proceed on their educational and career paths. Soft skills and overcoming behavioral barriers become increasingly important. Note the final row of Table D3 – a student's degree does not dictate his or her future jobs

Table D3. Students' Decisions, Considerations & Skills

Decision	Primary Considerations	Soft Skills & Behavioral Barriers
Going to College	Other options, e.g., work, military, gap year or equivalent	Imagine futures, career aspirations
Where to Apply	Reputation, selectivity, financial aid, location	Imagine futures, social features
Where to Enroll	Majors available, financial aid	Imagine futures, social features
General Major	Role models, interests, aptitude, motivation	Imagine futures, assess skills

Specific Major	Knowledge, role models, interests, aptitude, motivation	Imagine futures, assess skills
Career Path	36% in jobs with title engineer; 90% in jobs using engineering skills (NAP, 2018)	Imagine futures, assess skills

As indicated earlier, this case study was motivated by a desire to understand how government policies could enhance the STEM talent pipeline. The policy implications include the following:

- STEM preparation needs to start before college; middle school is ideal
- STEM motivation needs to start before college; middle school is ideal
- STEM investments in high school and middle schools increase talent pool
- STEM investments need to take into account both cognitive and soft skills
- Programmatic investments need to be balanced with financial aid

BEHAVIORAL ECONOMICS MODEL

Figure D1 summarizes all of the foregoing in terms of a behavioral economics model of students' decisions. Clearly, these decisions are highly influenced by context, which include family situation, gender, availability of role models, and the quality of K-12 schools in terms of teachers, STEM-related courses and experiences. Interest and aptitude are perhaps necessary factors, but are not sufficient if other factors are not aligned.

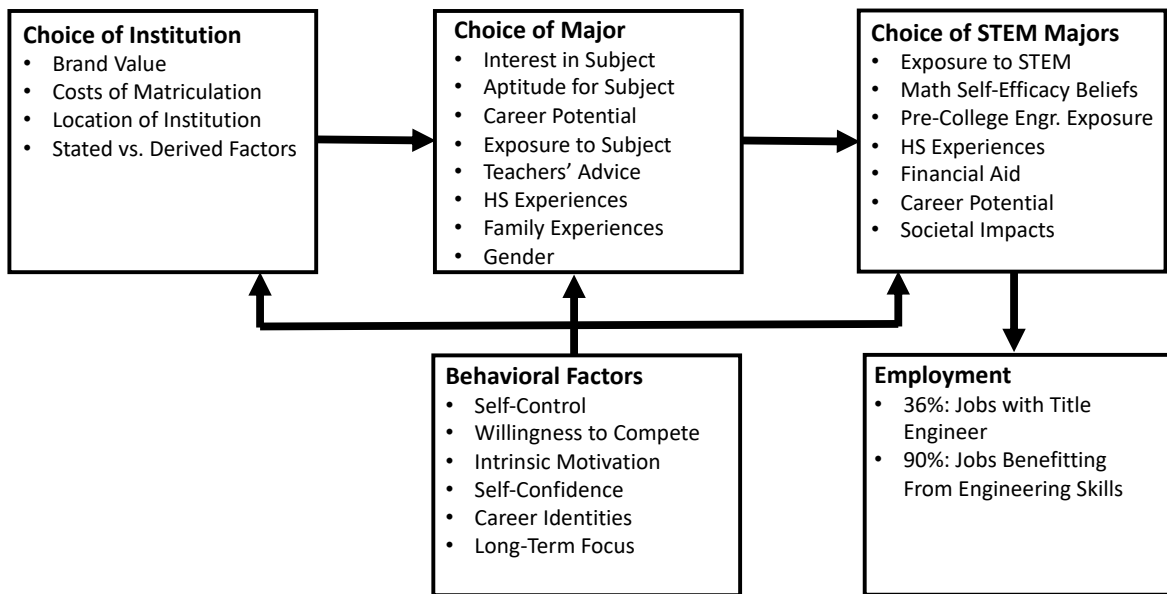


Figure D1. Behavioral Economics of Students' Decisions

Not all factors in Figure D1 can be influenced although they may be ascertained, particularly through direct interaction with a student. Several years ago, the author served on a National Academy of Engineering (NAE) panel to assess candidates for Congressionally-sponsored scholarships for Vietnamese students to matriculate in higher education in the US. This program was established with the leadership of Senator John McCain in the US Congress.

The candidates were interviewed in Hanoi and Ho Chi Minh City. They all had terrific grades and spoke impeccable English. By interviewing these students, as well as socializing with them outside the interview room, e.g., during lunches and receptions, it was possible to assess, if only implicitly, the behavioral factors in Figure 1. This enabled better consideration of whether a student was prepared to succeed in the US.

Another example of the impacts possible via personal interactions is the NAE Engineer Girl Program (<https://www.engineergirl.org/>). This highly successful, 20-year-old program is focused on increasing the matriculation of women in STEM programs. They have learned that success depends on targeting middle school girls; by high school, it is too late.

Another key to success has been to provide each girl a personal mentor, either a woman working in a STEM job, or perhaps another middle school or high school girl a few years older. These personal interactions provide opportunities for both

practical advice and influencing the behavioral factors in Figure D1. It seems that a “high touch” approach is needed to interact with the whole student.

POLICY IMPLICATIONS

Figure D1 can enable hypothesizing what types of interventions might help to increase the STEM talent pipeline -- and which might be unlikely to help. The goal is to empower students to make choices in their best interests. Institutions that provide offerings that meet students’ aspirations and needs will secure the monies needed for success. In contrast, institutions that insist on delivering dusty off-the-shelf content and experiences will likely struggle financially.

A first principle is that the policy portfolio of interest is intended to enhance the STEM talent pipeline, rather than subsidize challenged institutional budgets. The ideal policy portfolio will significantly increase the number of high school graduates that are “STEM ready.” This is essential to increasing the talent pipeline as, without this, only marginal increases are feasible – most of the current STEM-ready graduates are already enrolling in STEM degree programs.

Assuming success in this endeavor, the next challenge is to assure the success of the increased population of STEM students. This suggests a second principle. If the aim is for students to make better, well-informed decisions, then they should be empowered to make these decisions. Institutions need to shift from the sense that students are fortunate to be able matriculate with them to understanding that institutions are fortunate that students chose them. Institutions need to become truly student-centered.

K-12 Policies

Middle schools and high schools need to be incentivized to provide offerings that increase students’ interest and competencies. Such offerings require both human and financial resources that only a portion of schools have. Consequently, many schools do not have adequate offerings; hence, no one graduating from these schools can be STEM-ready. Directed grants could be offered for delivery of STEM courses in all schools.

Student STEM experiences have been found to increase interest and competencies. Beyond AP courses, and perhaps leveraging such coursework, a range of “camps” have been found to be successful, e.g., science and coding camps. Policies could enable providing students these experiences at no cost.

Paid internships with industry could be incentivized, as well as part-time jobs and summer jobs. Students could gain valuable hands-on experience as well as interact with STEM professionals. The first author attributes his decision to matriculate in engineering to working in a plumbing company, as well as cannibalizing junked cars for parts that he resold. Both experiences resulted in interest in how things worked.

To enhance students' abilities to make well-informed college decisions they need information on available programs and support services; success rates, costs and time until degree; and placement and salary statistics. Institutions should be incentivized to provide this information, possibly with real data rather than surveys that are self-reported.

Higher Education Policies

Policies could incentivize accessible offerings at community colleges and universities. These offerings would include a careful balance of theory and practice. Hands-on STEM would provide students with experiences performing experiments, creating artefacts, and evaluating these creations. Industry would play a significant role in designing these offerings.

Some offerings, selectively, would be vocationally oriented. Examples include aerospace, automotive, health, and semiconductor programs where most graduates seek employment in a particular industry. These programs would include jobs practicums to maximize successful pursuit of employment. This could be dovetailed with paid industry internships.

Institutions would be incentivized to provide knowledgeable and skilled counseling and coaching, delivered by professionals with substantial relevant industry experience. These people would get to know the whole student depicted in Figure 1. Beyond providing guidance, they would likely serve as STEM professional role models. Policies could include compensation incentives for these types of support.

More broadly, the support system envisioned would be comparable to that often provided to scholarship athletes. The goal is to foster knowledgeable, skilled, and motivated STEM professionals. Money would be provided to enable matriculation and graduation, including living expenses. Not every student would require the same level of monetary support, but money would not be a barrier to STEM pursuits.

As indicated earlier, the overall goal is to directly empower students rather than institutions. Thus, the monies involved would be provided to students. Institutions would compete to motivate students to spend these monies matriculating at their institutions. All interests would be aligned to foster a vibrant STEM talent pipeline.

Employment Policies

The pipeline does not stop upon student graduation. Incentives could be provided to encourage employee involvement in STEM professional societies, perhaps by providing societies monies to pay people's dues for an initial three years. Professional societies could be incentivized to enhance members' networking skills. Participation in regional alumni associations and their activities would also contribute.

Investments could be made in online mechanisms to help people identify and perhaps pursue STEM employment opportunities. Of course, such mechanisms are already commercially available, but they tend to cover all job opportunities. Jobs requiring specialized STEM skills could be presented in much more detail. Comparisons across companies in the same industry in terms of salaries and advancement, for example, would help people to fine tune their searching.

CONCLUSIONS

Enhancing the STEM talent pipeline requires that K-12 students make better, well-informed decisions about how to successfully pursue their aspirations. Enabling these decisions requires understanding the behavioral economics of students' decisions. A wide range of factors affect these decisions. Understanding these factors can help in the design of policy portfolios to enhance the STEM talent pipeline. This portfolio needs to address K-12, higher education, and employment. Investments need to address both the whole person and the life cycle of STEM education and employment.

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APPENDIX E: STUDENT RETENTION

Appendix D addressed students' attraction to STEM programs. This appendix highlights key findings on student retention in STEM education. Thus, we want to both attract students to STEM and retain them to graduation.

Chen, X., & Soldner, M. (2013). ***STEM Attrition: College Students' Paths Into and Out of STEM Fields***. Washington, DC: National Center for Educational Statistics.

- Half of STEM majors leave these majors. Half switch to non-STEM majors; the other half leave college. A greater percentage on non-STEM majors switched majors.
- The intensity of STEM course taking in the first year, the type of math courses taken in the first year, and the level of success in STEM courses had the greatest impact on attrition.
- Taking lighter credit loads in STEM courses in the first year, taking less challenging math courses in the first year, and performing poorly in STEM classes relative to non-STEM classes were associated with an increased probability of switching majors for STEM

Drew, S. (2011). Why Science Majors Change Their Minds (It's Just So Darn Hard). ***New York Times***, November 4.

- Deterrents include tough freshman classes, typically followed by two years of fairly abstract courses leading to a senior research or design project.
- The proliferation of grade inflation in the humanities and social sciences, which provides another incentive for students to leave STEM majors.
- Sophomore and junior years, which focus mainly on theory, remain a "weak link" in technical education.
- Students learn more by grappling with open-ended problems, like creating a computer game or designing an alternative energy system, than listening to lectures.
- Enable students to work closely with faculty members, build confidence and promote teamwork.
- Women want to see their schoolwork is connected to helping people, and the projects help them feel more comfortable in STEM fields

Hewson, S. (2019). ***The Mathematical Problems Faced by Advanced STEM Students***. Cambridge, UK: University of Cambridge, NRICH Mathematics Project.

- Overly procedural thinking
- Lack of ability to translate mathematical meaning to real-world meaning
- Lack of ability to make approximations or estimations
- Lack of multi-step problem solving skills
- Lack of practice

- Lack of confidence
- Lack of mathematical interest – too abstract, dull & difficult

Lombardi, J.V., & Capaldi, E.D. (1999). ***A Decade of Performance at the University of Florida, 1990-1999***. Gainesville, FL: University of Florida Foundation.

- Steady increase in National Merit Scholars
- Steady increase in freshman SAT scores
- Steady increase in number of BA/BS degrees awarded
- Percent women increased to 50% and minorities to 20%
- Degree tracking capabilities
- Academic Advising Center increased retention
- Doubling of sponsored research dollars per faculty member
- Tripling of total private gifts
- Quadrupling of endowment assets

McMurtie, B. (2021). Is Your Degree Program Too Complicated? Poor Design and Needless Bloat are Derailing Students, ***The Chronicle of Higher Education***, July 28.

- Degree requirements can grow without rhyme or reason
- Unneeded or poorly timed prerequisites and corequisites can add months onto the degree
- Tangled course sequencing can leave students spinning their wheels if they can't sign up for the classes they need when they need them.

These problems are particularly true in STEM fields, such as engineering

Cases reported

- University of New Mexico innovated with Curricular Analytics and raised four-year graduation rate from 13% to 35%
- Wright State University integrated Calculus I and II into engineering courses, increasing graduation rate from 51% to 70%
- Other universities employing Curricular Analytics include Colorado State, New Mexico State, University of South Florida, Utah State and Winston-Salem State University

Romash, Z.M. (2019). ***Leaving STEM: An Examination of the STEM to Non-STEM Major Change and How the STEM Curriculum Relates to Academic Achievement in Non-STEM Fields***. South Orange, NJ: Seton Hall, PhD Dissertation.

- STEM credits attempted is negatively associated with first year retention. Each unit increase in STEM credits attempted reduced the odds of persistence past the first year.

- Performance in college level math, introductory laboratory science and STEM courses plays an important role in determining students' level of academic achievement in non-STEM fields
- Females reach higher levels of academic achievement after leaving the STEM fields when compared to males.

Sithole, A., et al. (2017). Student Attraction, Persistence and Retention in STEM Programs: Successes and Continuing Challenges. *Higher Education Studies*, 7 (1), 2017, 46-49.

Pedagogy

- Likelihood of graduation highly correlated with freshman performance
- Emphasis on academic mastery of concepts rather than applications relevancy
- High workload of STEM courses discourages retention
- Success is highly correlated with quality of academic advising
- Faculty are not trained to be undergraduate advisors
- Faculty are not trained in culturally-sensitive advising

Students

- Lack of proficiency in mathematics
- Proficiency not necessarily leads to success in engineering
- Study habits have varying impacts
- Peer mentoring can help
- Time management, especially for students that work
- Intrinsic motivation
- K-12 experiences
- Social factors

Overall Recommendations

- Change Institutional Practices. There are several practices that institutions can revisit. For instance, using other feedback-soliciting methods aimed at understanding the needs of the students well before early grade reports. For example, surveys from these students would provide a lead to attractors in these programs which may not be available in STEM fields. Such methods could involve early reflection papers or early course surveys
- Provide Necessary Support to STEM Students. This could be in the form of student peer mentoring programs. These programs require a sustainable source of funding to compensate student mentors. Institutional funding challenges for such programs can be alleviated through collaboration between STEM programs and private organizations. The collaborations also help to strengthen bridges between STEM faculty and corporate organizations, which is fundamental to the training and placement of STEM

graduates. In addition, teachers should seek funding from Foundations and local private funding agencies

- Professional Development of Teachers. This needs to be done systematically and tailor-made to STEM teachers by conducting a needs assessment of the STEM teachers and then designing programs that address the identified needs. Also, there is need to address programming issues such when to conduct the professional development, duration of programs, and incentives for participating in the programs. It's also beneficial to include administrators in the professional development programs to ensure support for the STEM teachers.

Song, Y., et al., (2019). *Why Students Leave STEM*. Long Beach, CA: California State University.

Factors Affecting STEM Retention

- Student Aptitude – High School GPA & SAT scores
- Student Preparation – courses & experiences
- Class Size – in early math, chemistry & physics courses
- Quality of Teaching
- Quality of Advising
- Quality of Tutoring
- Higher Grades in Non-STEM Courses

Witteveen, D., & Attewell, P. (2020). The STEM grading penalty: An alternative to the “leaky pipeline” hypothesis. *Science Education*, 2020(104), 714–735.

- Relatively lower grades that many individuals earn in STEM courses compared to their non-STEM courses
- The size of an undergraduate's “STEM-grading penalty”—an individual grading disparity—in the first couple of college semesters is significantly associated with the probability of leaving STEM.
- The influence of this STEM-penalty on STEM graduation chances is robust to college students' variation in both general academic achievement and STEM-specific preparation, thereby eliminating a large portion of the effect

Figure E1 summarizes the factors this literature highlights as means to increase retention.

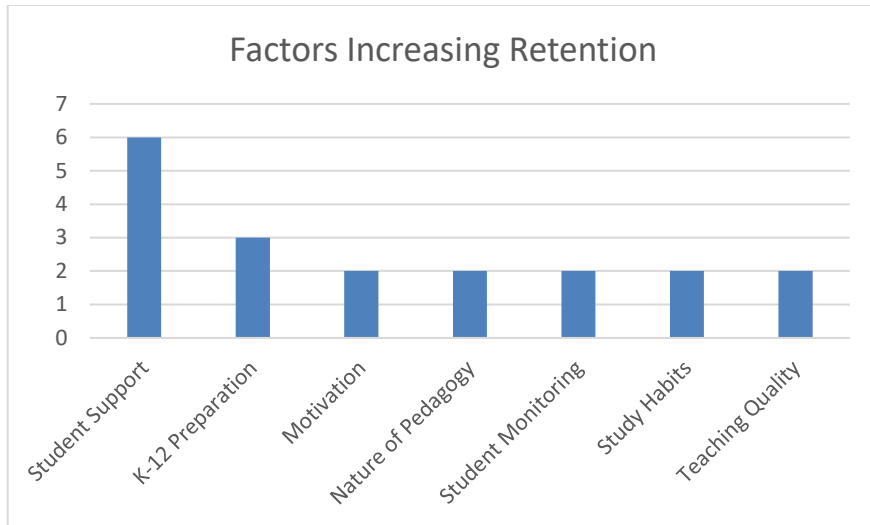


Figure E1. Factors Increasing STEM Retention