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ARTICLE

Two Strategies to Secure Science, Technology, Engineering, and Mathematics (STEM) Capital in the United States

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The study proposes two strategies for education planners and governments to secure Science, Technology, Engineering, and Mathematics (STEM) capital. First, this paper highlights that essential knowledge and skills for STEM students are differentiated by their major. For instance, the knowledge of English ranked first in Science, and the knowledge of mathematics placed first in Technology. Second, the study employs panel models to exhibit factors that are related to the proportion of STEM workers in the U.S. states between 2003 and 2012. The panel models highlight the variables associated with the gradient of STEM workers as follows: (1) industrial structure, (2) housing price, and (3) foreign-born people. Therefore, governments and education planners should develop education policies or training programs differentiated by the STEM fields to provide proper knowledge and skills for STEM students and take into account the important factors to secure STEM capital.

Keywords: STEM·Education·Panel·Science, Technology, Engineering, and Mathematics

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Introduction

Science, Technology, Engineering, and Mathematics (STEM) is the future of the U.S. economy. Since 2004, the number of STEM jobs increased by 16 percent, from 14.2 million to 16.5 million jobs in 2012 (United States Government Accountability Office, 2014). In 2013, estimates of the size of the Science and Engineering workforce ranged from approximately 6 million to more than 21 million depending on the definition used. Half of the workers in Science and Engineering occupations earned $81,000 or more in 2014, which is more than double the median salaries ($36,000) of the total workforce (BLS, 2014). In this regard, STEM workers can be considered as the capital for economic development in the human capital perspective. Also, advancement in the STEM has long been central to America's ability to manufacture better and smarter products, improve health care, develop cleaner and more efficient domestic energy sources, preserve the environment, safeguard national security, and grow the economy. For the United States to maintain its preeminent position in the world, it will be essential that the Nation continues to lead in STEM (National Science and Technology Council, 2013).

In this background, officials from federal agencies with education programs aimed at improving America's competitiveness in STEM engaged in a yearlong endeavor to assess their programs' success and to identify areas for improvement for current and future programs (U.S. Department of Education, 2007). However, numerous reports detail the growing concern of policymakers and industry leaders regarding a shortage in the STEM workforce believed necessary to sustain the U.S. innovation enterprise, global competitiveness, and national security (see e.g., Business Roundtable, 2005; National Science and Technology Council, 2000, 2013; National Science Board, 2003; Xue and Larson, 2015). For example, the United States currently ranks 20th among all nations in the proportion of 24-year-olds who earn degrees in natural science and engineering. Once a leader in STEM education, the United States is now far behind many countries on several measures (Congressional Research Service, 2008). National Science and Technology Council (2013) reported that current educational pathways are not leading to a sufficiently large and well-trained STEM workforce to achieve this goal. Also, U.S. Department of Education (2007) stated that there is a general dearth of evidence of effective practices and activities in STEM education. NGSS Lead States (2013) pointed out that the United States has a leaky K–12 STEM talent pipeline, with too few students entering STEM majors and careers at every level—from those with relevant postsecondary certificates to Ph.Ds. Not only that, according to a survey, 86% of US people believe that the United States should increase the number of workers with a background in science and mathematics or America's ability to compete in the global economy will be diminished (National Research Council, 2007).

On this ground, scholars have tried to suggest better ideas to improve STEM education and exhibit the effects of STEM, and the prior research of STEM can be divided into four study areas:

1. STEM education programs (see, e.g., Atkinson et al., 2007; Bybee and Fuchs, 2006; Congressional Research Service, 2008; Dickman et al., 2009; Epstein and Miller, 2011; Modi et al., 2012; National Research Council, 2014; Slovacek et al., 2011; Tyson et al., 2007; Wingenbach et al., 2007; U.S. Department of Education, 2007).
2. Ethnic barriers for Minorities in STEM (see, e.g., Clark, 1999; Cole and Espinoza, 2008; Maton and Hrabowski III, 2004; May and Chubin, 2003).
3. The gap between men and women in STEM (see, e.g., Blickenstaff, 2005; Milgram, 2011; Miyake et al., 2010; Smeding, 2012; Stout et al., 2011).
4. The number and wage of STEM workers (see, e.g., BLS, 2014; Langdon et al., 2011; National Science Foundation, 2016; United States Government Accountability Office, 2014).

As the prior research indicated, while many articles and reports have analyzed the STEM fields, the essential knowledge and skills in STEM occupations and the factors that are related to the proportion of STEM workers in the U.S. states are barely highlighted in the prior research. They should be explored because understanding the required knowledge and skills from STEM

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workers and the factors related to the STEM workers allows educators, curriculum developers, and policy practitioners to develop a better tool for STEM programs, provide better environments for STEM students, and secure STEM capital (see e.g., NGSS Lead States, 2013).

Therefore, this study suggests two strategies to secure STEM capital in the United States. The first strategy is to highlight the essential knowledge and skills in each STEM field by analyzing STEM occupations, which was barely highlighted in the previous research. This study explores the STEM knowledge and skills to grasp what kind of knowledge and skills are required for the STEM students to enter the STEM fields. To be specific, STEM workers should have not only STEM knowledge and skills but also other essential abilities, such as the knowledge of administration and management and communication skill, to be a talented worker in the field. Furthermore, to the best of my knowledge, the priority of knowledge and the ranking of knowledge in each STEM field has not been separately highlighted in the prior research, despite the importance of those. For example, it may be arguable which knowledge is more important between engineering and mathematics in the science field, and this study explores these undiscovered issues.

The second strategy is to exhibit the spatial pattern, the trend, and the factors related to the proportion of STEM workers in each state to promote STEM environments. The study highlights them by analyzing 50 states and the District of Columbia in the U.S. from 2003 to 2012, using descriptive analyses and panel models. This implication can contribute to STEM learning ecosystem (see http://stemecosystems.org/) by understanding the regional conditions for creating an ecosystem of high-quality productive STEM environments (see e.g., National Research Council, 2015). The data used in this article are from various sources, such as O*NET, U.S. Census Bureau, Lincoln Institute, National Science Foundation, and U.S. Department of Justice.

The Required Knowledge and Skills for STEM

In order to understand the required knowledge and skills in the STEM field, the study first explores the definition and the boundary of STEM. STEM is an acronym often used to refer to occupations, as well as fields of study, in science, technology, engineering, and math. The definition of STEM can vary, depending on the group using it (Jones, 2014). STEM fields can include a wide range of disciplines. For example, the National Science Foundation (NSF) defines STEM fields broadly, including not only the common categories of mathematics, natural sciences, engineering, and computer and information sciences, but also such social/behavioral sciences as psychology, economics, sociology, and political science (Green, 2007). Many recent federal and state legislative efforts, however, are aimed at improving STEM education mainly in mathematics, natural sciences, engineering, and technologies (Kuenzi et al., 2006; National Governors Association, 2007, 2011). For this reason, this Statistics, in Brief, excludes social/behavioral sciences from the definition of STEM fields (Chen, 2009). The study classifies STEM occupations based on the definition of O*NET, which is the United States' primary source of occupational information given that one of the purposes in this article is to provide the information for policymakers and STEM students to grasp the required knowledge and skills to work in the STEM field. The O*NET data collection program provides several hundred ratings, based on responses by the sampled workers to the O*NET questionnaires. The O*NET database contains hundreds of standardized and occupation-specific descriptors on almost 1,000 occupations covering the entire U.S. economy. These occupations have been defined based on the Standard Occupational Classification (SOC) system. Two major sources of information are used to create the establishment sampling frame. First, a list covering nearly 17 million establishments in the United States is constructed from the database list of U.S. establishment locations. Additional information from the Occupational Employment Statistics survey, conducted by Bureau of Labor Statistics, is merged with the database list of establishments. Workers sampled from establishments are randomly assigned to answer only one of the questionnaires. For occupations where it would be difficult to sample workers, such as those that have a small number of workers or ones in which employees work in remote locations, occupation experts are identified and sampled from professional and/or trade association membership lists. The occupation experts complete multiple questionnaires. In addition to the questionnaires completed by workers and occupation experts, additional ratings are provided by occupation analysts. Responses from all three sources--workers, occupation experts, and occupation analysts--are used to provide complete information for each occupation. Abilities and skills information are developed by occupational analysts using the updated information from incumbent workers (see www.onetcenter.org for the detailed information). The research analyzes the importance of 33 knowledge categories and 35 skill categories for STEM workers in the database.

After analyzing the O*NET data, in Science, English is the most important knowledge among 33 categories of knowledge, even higher than knowledge of mathematics and knowledge of computers and electronics (see **Table 1**). This result implies that workers in the Science field need more collaborations, communication, and discussion than those in the Technology, Engineering, and Mathematics fields. The English language also plays a pivotal role in other STEM fields. For example, it ranked second highest after knowledge of mathematics in Technology and ranked third in Engineering and Mathematics, respectively.

Technology needs knowledge of mathematics as a top priority, which is even superior to knowledge of engineering and technology or knowledge of computers and electronics. English language and chemistry also placed high in Technology. To be specific, English language placed second over knowledge of computers and electronics and knowledge of engineering and technology. Chemistry ranked fourth in the Technology field even though it did not get any rank in the top ten in Science, Engineering, and Mathematics, implying that Technology requires the acquisition of chemistry knowledge more than other STEM fields.

Engineering requires knowledge of engineering and technology as the top priorities, which are directly associated with the Engineering field, and mathematics ranked second in the Engineering field. One interesting finding in Engineering is that design ranked fourth, which did not rank within the top ten in other STEM fields, and production and processing ranked within the top ten only in the Engineering field.

Table 1. The importance of knowledge and skills in STEM

	Knowledge (score)				Skill (score)			
	S	T	E	M	S	T	E	M
1	English Language (71.0)	Mathematics (66.0)	Engineering and Technology (81.3)	Mathematics (95.1)	Critical Thinking (70.1)	Critical Thinking (67.4)	Critical Thinking (70.6)	Mathematics (83.4)
2	Mathematics (60.9)	English Language (63.2)	Mathematics (73.9)	Computers and Electronics (71.6)	Active Listening (69.6)	Reading Comprehension (66.8)	Reading Comprehension (69.0)	Critical Thinking (78.1)
3	Computers and Electronics (60)	Computers and Electronics (61.5)	English Language (69.7)	English Language (70.8)	Speaking (68.9)	Active Listening (64.9)	Active Listening (67.8)	Reading Comprehension (77.2)
4	Education and Training (53.7)	Chemistry (52.4)	Design (69.4)	Education and Training (47.1)	Reading Comprehension (68.8)	Speaking (60.9)	Complex Problem Solving (65.5)	Active Listening (72.4)
5	Customer and Personal Service (53.6)	Engineering and Technology (52.1)	Computers and Electronics (65.2)	Physics (42.6)	Complex Problem Solving (64.1)	Monitoring (58.5)	Speaking (65.3)	Complex Problem Solving (70.7)
6	Administration and Management (53.2)	Physics (49.1)	Physics (59.7)	Engineering and Technology (42.3)	Writing (63.9)	Writing (58.4)	Judgment and Decision Making (62.0)	Speaking (70.4)
7	Biology (44.4)	Education and Training (46.8)	Mechanical (59.4)	Administration and Management (40.7)	Judgment and Decision Making (63.7)	Complex Problem Solving (57.2)	Writing (61.4)	Judgment and Decision Making (68.3)
8	Clerical (42.6)	Customer and Personal Service (44.7)	Administration and Management (53.3)	Customer and Personal Service (35.6)	Monitoring (61.4)	Judgment and Decision Making (56.5)	Monitoring (58.7)	Active Learning (67.3)
9	Law and Government (40.9)	Mechanical (44.6)	Customer and Personal Service (51.6)	Economics and Accounting (31.8)	Active Learning (60.6)	Active Learning (56.3)	Active Learning (58.1)	Writing (66.3)
10	Communications and Media (40.1)	Public Safety and Security (42.4)	Production and Processing (51.6)	Communications and Media (31.4)	Time Management (56.8)	Mathematics (53.9)	Time Management (55.5)	Learning Strategies (58.2)

Note: The score scale is from 0 to 100 is calculated based on O*NET data

Table 2. Changes of STEM between 2003 and 2012 by states

	Low (2003)	High (2003)
Low (2012)	AL, AZ, AR, FL, HI, ID, IN, IA, KY, LA, ME, MS, MO, MT, NE, NV, NM, NY, NC, ND, OH, OK, OR, PA, RI, SC, SD, TN, VT, WV, WI, WY (type 1: 32 states)	DE, MI (type 2: 2 states)
High (2012)	AK, NH, UT (type 3: 3 states)	CA, CO, CT, DC, GA, IL, KS, MD, MA, MN, NJ, TX, VA, WA (type 4: 13 states and the District of Columbia)

The knowledge of mathematics ranked first in the Mathematics field, and knowledge of computers and electronics ranked second, which is higher than other STEM fields. English language placed third in Mathematics, implying that collaborations, communication, and discussion also play an essential role in the field. Knowledge of economics and accounting ranked ninth, and they only ranked in the Mathematics among all STEM fields.

One important finding in the knowledge sector is that the knowledge of mathematics ranked first or second in all STEM sectors, and this result enables us to interpret that Mathematics is the background knowledge in the STEM fields, and we should teach mathematics with a higher priority to STEM workers and students. Another crucial implication of this study is that English ranked within top three in all STEM fields. This result highlights that English plays an important role in the STEM fields as much as other knowledge, such as mathematics or engineering and technology, meaning that STEM students need to learn how to do collaborations, communication, and discussion with other people in English.

Next, in the skill section, critical thinking is the highest priority in all STEM fields except for Mathematics (it ranked second highest after knowledge of mathematics in the Mathematics field). This result is consistent with the prior studies. For example, BLS (2014) reported that STEM workers must have strong thinking and communications skills. Critical and creative thinking help STEM workers in problem-solving to detect mistakes, gather relevant information, and understand how different parts or systems interact with each other. This result demonstrates that critical thinking plays a pivotal role in working in the STEM fields. Communication skills, such as active listening and speaking, ranked high in all STEM fields (S: second, T: third, E: third, and M: fourth for active listening and S: third, T: fourth, E: fifth, and M: sixth for speaking). This result is also consistent with that communication skills are important for working well with others and conveying information clearly, both orally and in writing for STEM (BLS, 2014). One notable finding in the skill section is that Science, Technology, and Engineering show the similar priorities of skills within the top five, whereas Mathematics shows a different characteristic. For instance, communication skills ranked higher in other STEM fields than Mathematics. This seems that solving problems or finding optimization is more important than collaborations or communication in the Mathematics field.

In sum, each STEM field shows different priorities of knowledge and skills to work in their field. For example, Science has the top priority in the English language, whereas Technology needs knowledge of mathematics taking precedence over knowledge of engineering and technology. In the skill section, critical thinking is the main skill of the STEM workforce, even though Mathematics shows a different characteristic from other STEM fields. As such, we should develop STEM curriculums based on the understanding of knowledge and skills in the STEM fields. For the purpose, the findings of this article for knowledge and skills in STEM provide a new vision for STEM education and help develop certain conceptual curriculum.

The Trend of STEM in the United States

This study first demonstrates the trend of STEM workers in the U.S. between 2003 and 2012 by analyzing the proportion of STEM workers in the general population. This study divides the trends of 50 states and the District of Columbia into four categories in reference to the average of STEM workers in the United States: the year 2003 and 2012 are both lower than the average (type 1), the year 2003 is higher, and 2012 is lower than the average (type 2), the year 2003 is lower, and 2012 is higher than the average (type 3), and the year 2003 and 2012 are both higher than the average (type 4). **Table 2** above demonstrates that type 1 has 32 states, such as AL and AZ, type 2 comprises only two states (DE and MI), type 3 consists of three states (AK, NH, and UT), and type 4 includes 13 states, such as CA and CO, and the District of Columbia. **Figure 1** demonstrates that the gradients of the STEM proportion between 2003 and 2012 vary across the states. For example, New Hampshire's proportion of STEM fell until 2007, and it rose over the average since 2007. In comparison, Delaware's proportion dropped after 2004, declined until 2008, rose over the U.S. average until 2010, and then decreased below the average again (see **Figure 1**). **Table 2** and **Figure 1** imply that there are some factors affecting the gradients of STEM proportion in the states, and they should be highlighted to secure STEM capital.

To be specific, Alaska shows the highest gradient of 3.50%, followed by Virginia (2.24%) (see **Table 3**). This result may have resulted from the states' STEM education policies, which have encouraged students to enter the STEM fields. For example, Alaska has developed well organized STEM programs for their students. The Alaska Native Science & Engineering Program (ANSEP) is one of the most successful and cost-effective STEM education programs in the US. It is one of seven finalists for the Harvard Kennedy School of Government 2018 Innovations in American Government Award. ANSEP has evolved into a longitudinal education model that provides a continuous string of components beginning with students in sixth grade and on through high school, into science and engineering undergraduate degree programs and through graduate school to the Ph.D. Students who start in ANSEP in middle school or early in high school can earn the full Alaska Performance Scholarship regardless of where they live (see http://www.ansep.net/). The program, which has a total operating budget of approximately $8 million a year, is a partnership between the University of Alaska system and public and private entities. It is being used as a model for other states seeking to bring underserved communities into STEM education (see https://www.usnews.com/news/best-states/articles/2018-03-29/native-alaskans-in-stem-program-work-to-make-lives-better). Also, the government has worked with teachers and students, government and non-government organizations, not-for-profits, and increasingly with Alaska business and industry to address the current and future STEM needs of the state. For instance, Juneau Economic Development Council (JEDC) recognizes STEM education as an economic imperative and tries to increase student interest and competencies in STEM fields, organized around three strategies: facilitate professional development of teachers; offer STEM enrichment activities to students; and, participate in advocacy and outreach to build public awareness and support (see http://www.jedc.org/stemak/).

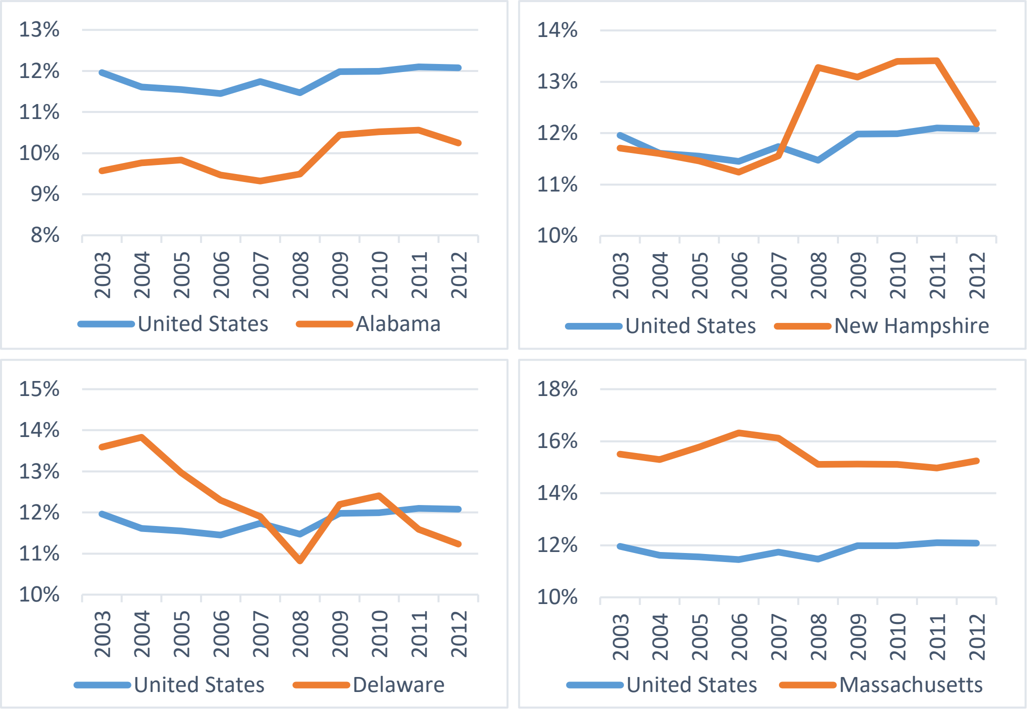

Figure 1. The proportion of STEM in four states between 2003 and 2012

Table 3. The gradients of the states in the top 10 and bottom 10

	TOP 10				BOTTOM 10			
	State	2003 (%)	2012 (%)	Gradient (%)	State	2003 (%)	2012 (%)	Gradient (%)
1	Alaska	10.08	13.58	3.50	Delaware	13.59	11.23	-2.36
2	Virginia	15.65	17.89	2.24	Vermont	11.47	9.22	-2.25
3	DC	12.84	14.83	1.99	Arizona	11.74	10.52	-1.22
4	Rhode Island	8.38	9.94	1.56	Idaho	11.94	10.91	-1.03
5	Colorado	14.60	15.83	1.23	Michigan	12.85	11.82	-1.03
6	Georgia	12.21	13.41	1.20	Texas	14.39	13.37	-1.02
7	Hawaii	5.62	6.79	1.17	New York	11.11	10.21	-0.90
8	Wisconsin	9.82	10.99	1.17	Washington	17.51	16.65	-0.86
9	Minnesota	13.27	14.33	1.06	Kansas	13.97	13.13	-0.84
10	Maryland	15.12	16.14	1.02	Nebraska	8.90	8.29	-0.61

Virginia also have put a large effort for STEM education to encourage students to enter STEM fields. For example, the Virginia Department of Education has aligned the vision for STEM education with the knowledge, skills, experiences and attributes that students must attain to be successful in college and/or the work force and to be life ready (see http://www.doe.virginia.gov/instruction/stem/index.shtml). Also, governor's STEM academies design to expand options for the general student population to acquire STEM literacy and other critical skills, knowledge and credentials that will prepare them for high-demand, high-wage, and high-skill careers in Virginia. Each academy is a partnership among school divisions, postsecondary institutions and business and industry (see http://www.doe.virginia.gov/instruction/career_technical/gov_academies/index.shtml).

Next, the research highlights the ranking of the number of STEM workers in U.S. states in the year 2012 based on Occupational Employment Statistics released by the United States Department of Labor. California ranked first in all STEM fields, meaning that California plays a vital role in STEM for the United States (see **Table 4**). After California, Texas ranked second in all STEM fields except for Mathematics (New York placed second, and Texas ranked third in Mathematics). The other noteworthy characteristics are that Engineering has a higher value in Florida (third) than other stem fields, and Technology shows a high number of technology workers in Michigan (fourth) compared to others (see **Figure 2**).

Overall, California and Texas share an outstanding number of STEM workers; those regions have 21% (California: 13% and Texas: 8%) of STEM workers in the United States (see **Figure 3**). This result can be caused by the fact that they have continuously tried to increase STEM workers for their regions. For example, California's schools have begun implementing Common Core mathematics standards and the Next Generation Science Standards (see http://www.corestandards.org/Math/ and https://www.nextgenscience.org/). With the state strategy for school funding, called the Local Control Funding Formula (see https://www.cde.ca.gov/fg/aa/lc/lcffoverview.asp), school districts have an unprecedented opportunity to improve student outcomes by investing more budget dollars toward the teaching of critical subjects, including STEM (see https://www.childrennow.org/files/2414/8036/4231/CN-STEM-Education.pdf). California builds the California STEM Learning Network, which is a statewide network of champions across the public and private sectors to ensure that all California students have access to high quality STEM learning opportunities that prepare them for success in college, career and their daily lives. This network is working to shape and implement a common agenda to advance policies and programs that increase quality, access and innovation in STEM education across each region and throughout the state (see https://www.ncstemcenter.org/resources/california-stem-learning-network/).

Table 4. The ranking number of STEM workers in 2012

	S	T	E	M	STEM
	State (N)	State (N)	State (N)	State (N)	State (N)
1	California (1,118,170)	California (79,660)	California (440,160)	California (41,850)	California (1,679,840)
2	Texas (687,910)	Texas (41,850)	Texas (346,030)	New York (24,400)	Texas (1,098,810)
3	New York (508,790)	New York (29,380)	Florida (170,730)	Texas (23,020)	New York (727,570)
4	Florida (436,510)	Michigan (24,500)	New York (165,000)	Florida (20,150)	Florida (650,240)
5	Illinois (382,750)	Illinois (23,830)	Pennsylvania (151,030)	Illinois (15,640)	Illinois (557,660)
6	Virginia (350,670)	Florida (22,850)	Michigan (151,010)	New Jersey (15,240)	Pennsylvania (514,000)
7	Pennsylvania (327,310)	Pennsylvania (22,100)	Ohio (137,000)	Virginia (13,810)	Virginia (495,560)
8	Ohio (313,130)	Ohio (21,110)	Illinois (135,440)	Maryland (13,700)	Ohio (484,030)
9	New Jersey (308,230)	Massachusetts (20,560)	Virginia (115,660)	Pennsylvania (13,560)	Michigan (444,750)
10	Massachusetts (279,350)	Maryland (18,740)	Washington (103,960)	Ohio (12,790)	New Jersey (433,230)
11	North Carolina (268,890)	New Jersey (18,130)	Massachusetts (100,860)	Michigan (12,440)	Massachusetts (410,950)
12	Michigan (256,800)	Virginia (15,420)	North Carolina (97,390)	North Carolina (10,810)	North Carolina (388,580)
13	Georgia (252,800)	Washington (15,320)	Georgia (92,990)	Massachusetts (10,180)	Washington (378,380)
14	Washington (251,640)	Georgia (13,680)	New Jersey (91,630)	Georgia (8,000)	Georgia (367,470)
15	Maryland (231,960)	Indiana (12,830)	Maryland (85,710)	Colorado (7,520)	Maryland (350,110)
16	Colorado (216,430)	Wisconsin (12,090)	Colorado (74,750)	Washington (7,460)	Colorado (309,160)
17	Minnesota (206,450)	Oregon (12,030)	Arizona (74,100)	Minnesota (6,880)	Minnesota (295,250)
18	Missouri (178,610)	North Carolina (11,490)	Indiana (73,830)	D.C. (6,480)	Missouri (253,540)
19	Wisconsin (163,380)	Tennessee (11,490)	Minnesota (70,810)	Indiana (6,150)	Arizona (247,930)
20	Arizona (156,790)	Arizona (11,260)	Wisconsin (67,480)	Arizona (5,780)	Wisconsin (247,520)

Note: The ranking is calculated based on Occupational Employment Statistics released by United States Department of Labor.

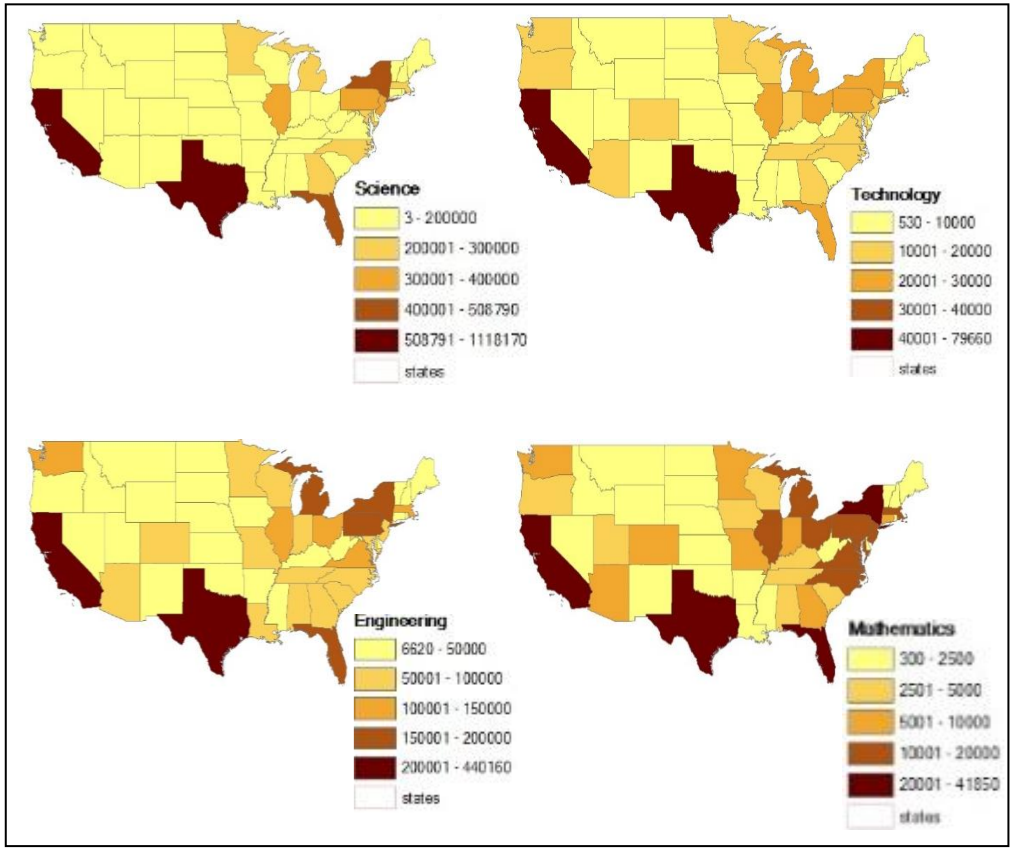

Figure 2. The spatial patterns of Science, Technology, Engineering, and Mathematics in the U.S.

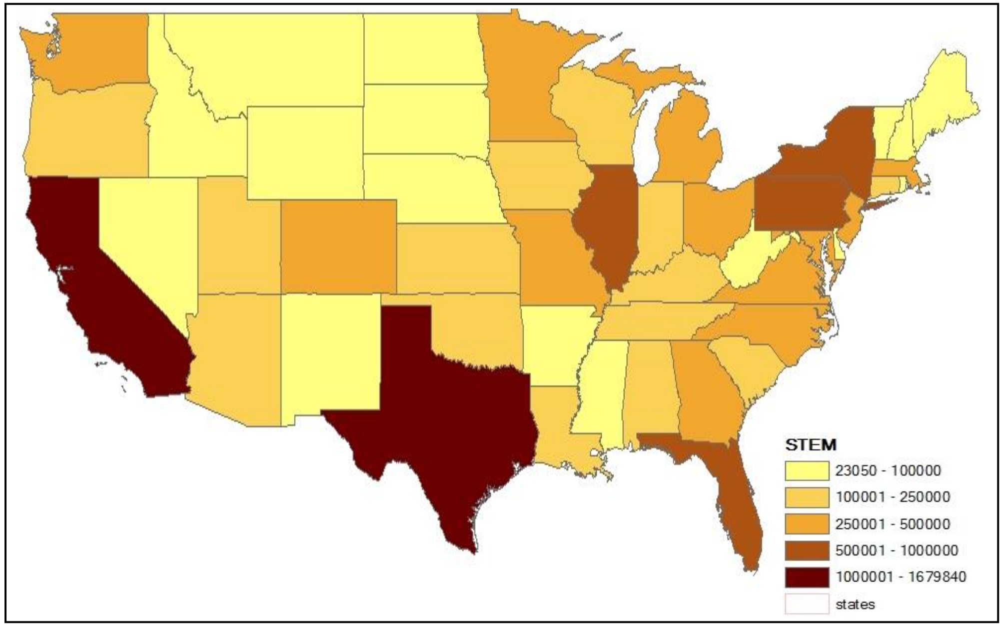

Figure 3. The number of STEM workers in USA

The Texas government implements a T-STEM (Texas-STEM) program, which focuses on improving instruction and academic performance in science and mathematics-related subjects and increasing the number of students who study and enter STEM careers (see https://tea.texas.gov/T-STEM/). Also, Educate Texas' STEM programs bring together state agencies and school districts to focus on STEM education, with goals to strengthen instruction and academics, build relationships with industry experts and the business community, prepare students for STEM careers, and create best practices to use in other school districts (see https://www.edtx.org/our-work/stem).

Determinants of STEM Workers in the United States

The study employs panel models to highlight factors related to the proportion of the STEM workers in the U.S. states between 2003 and 2012. The panel model explores a class of linear econometric models that commonly arise when time series and cross-sectional data are combined. The panel model allows researchers to measure the effects of variables more accurately because it addresses a number of important factors that cannot be formulated in other models, such as ordinary linear square regression, by using both cross-sectional and time-series data sets. This model can be divided into fixed effects model and random effects model, assuming the difference between individuals and times in the data to check the cross-sectional effect and time-series effect. The fixed effects model checks if intercepts vary across groups or time-series, whereas the random effects model checks differences in error variances. This study applies the fixed effect model to the equation because the *p*-value for the Hausman test is less than 0.01 (*p*-value=0.0079). This research explores observations that cover the period from 2003 to 2012 and one panel of data consisting of U.S. states.

The basic equation for the fixed effects model is as follows:

$$Y_{it} = \beta_1 X_{it} + \alpha_i + u_{it}$$

where

- α_i (I = 1….n) is the unknown intercept for each entity (n entity-specific intercepts)
- Y_{it} is the dependent variable where I =entity and t = time
- X_{it} represents one independent variable
- β_1 is the coefficient for that independent variable
- u_{it} is the error term

In this study, the dependent variable (Y) is the proportion of the STEM workers in the general population. The study considers five characteristics of regions as independent variables; regions' economic, housing, ethnic, industrial, and geographical environment. First of all, the study uses the Gross Domestic Product (GDP) as a proxy variable of the economic environment in the region given that it shows the productivity of the region. Next, housing environments may play an important role in the proportion of STEM workers because it is one of the most critical matters in human life. This study added two housing variables in the panel model. First, a house value can affect the STEM workers' decision of where to live. If the house value is high, people may feel onerous to pay a high rent fee or purchase a house for their living except for some rich people. Another explanatory variable related to the housing condition is a crime rate (property crime rate) given that better places usually have a lower crime rate, and this study assumes that STEM workers prefer to live in a region with a low crime rate.

The ethnic environment can be one of the independent variables to explain the proportion of STEM workers. The racial composition in a region has been some of the most significant reasons for choosing a residence. For example, white STEM workers may prefer to live in the environment surrounded by white people, and some other ethnic STEM workers want to live with whites because a region with a high proportion of whites is more likely to have good schools, housing conditions, and environments (see e.g., Bailey, 1959; Price-Spratlen and Guest, 2002). In contrast, in the case of foreign-born STEM workers, they may feel comfortable when their regions are open to other races and tend to hang out with similar ethnicities. Therefore, they may prefer a region with a higher proportion of foreign people.

Fourthly, the study employs three industrial variables for the industrial structure in the region; manufacturing, science and technology service, and education. Manufacturing is mostly associated with the STEM field and needs to hire many STEM workers. For example, in 2011, a survey of manufacturers found that as many as 600,000 jobs remained unfilled because there is a lack of qualified candidates for technical positions requiring STEM skills (Morrison et al., 2011). Manufacturing, therefore, can hire a lot of STEM workers and affect the proportion of STEM workers in the general population. On the other hand, STEM workers may not choose a region with a high proportion of manufacturing because manufacturing is recognized as a low-tech industry, and a manufacturing-centered region is likely to be a declining area in our information and technology-based societies. Instead, STEM workers prefer high-value added industries for higher salaries and careers. The study chooses science and technology service industries as one of the independent variables to check their preference and control the industrial condition. For example, science and technology service has many high value-added industries, which are directly related with the STEM field, such as engineering services, computer systems design and related services, and scientific research and development Services.

Also, the study added education industries as an independent variable because they include some postsecondary teachers, such as biological science teacher and mathematical science teacher, which are categorized in the STEM fields. Education industries therefore can affect some parts of job creation in STEM. For more accurate analysis, the study only considers education industries in post-secondary level and excludes elementary and secondary level because they are not included in the STEM occupation categories.

Lastly, the study set The Sun Belt as a dummy variable to control a geographical condition. The Sun Belt is known as the warm weather and higher productivity region. This condition can affect the proportion of STEM workers in the areas.

After the panel analysis, one-way and two-way effect models have the same result on the signs of the values, but coefficient values are slightly different (see **Table 5**). First of all, the proportion of STEM workers exhibits a negatively significant sign on the home value, implying that a high home value reduces the proportion of STEM workers in a region.

Among the industry variables, science and technology service have the highest positive elasticity, whereas manufacturing shows the highest negative elasticity not only among the industry variables, but also among all variables. To be specific, if science and technology service increases 1%, then the proportion of STEM workers increase by about two times (one-way: 1.8% and two-way: 1.9%), meaning that science and technology industries have a high job creation effect for stem workers. In contrast, if Manufacturing increases 1%, then the proportion of STEM workers decreases roughly by two times (one way: -1.8% and two way: -1.6%), implying that STEM workers avoid Manufacturing-centered regions. Education is insignificant in the panel models, and this result seems that the proportion of postsecondary occupations has a minor share in the STEM field and has a small job creation effect.

Table 5. The panel result

	One-way fixed model	Two-way fixed model
Constant	**15.450	-2.525
The GDP	-0.384	0.949
Home value	**-0.357	**-0.259
Crime rate	-0.172	-0.094
White people	-0.002	-0.002
Foreign born	***0.257	**0.218
Manufacturing	***-1.757	**-1.627
Science and Technology service	**1.806	**1.911
Education	0.511	0.666
The Sun Belt		-0.496

Note: Variables transferred into log values except percentage variables
*** <0.01 ** <0.05 * < 0.1
The Sun Belt in the one-way fixed model omitted because of collinearity

Finally, the proportion of foreign-born people reveals a positive sign to the proportion of STEM workers times (one way: 0.3% and two way: 0.2%). This result can be interpreted as STEM workers prefer open and tolerant environments given that the number (or proportion) of foreign-born people is often used as a diversity or openness index. As we can see in the Florida (2014)'s perspective, diversity is one of the most essential values in the modern societies, and creativity, which is one of the most valuable resources for human life, stems more from the regions that respect diversity and tolerance.

In a nutshell, science and technology service has the highest positive elasticity, whereas manufacturing shows the highest negative impact on the proportion of STEM workers among all variables. After those, the home value has a negative effect, whereas foreign-born people are positive to the proportion of STEM workers. Therefore, the factors affecting the proportion of stem workers in this article are as follows: (1) industrial structure, (2) the house value, and (3) foreign-born people.

Conclusions

Human capital has been increasingly emphasized in urban economic growth literature (Cover et al., 2011; Jones, 2014; Langdon et al., 2011; Glaeser and Shapino, 2003; Shapiro, 2006; Simon and Nardinelli, 2002), and STEM workers are considered as the human capital in our technology-based societies. STEM occupations play an instrumental role in expanding scientific frontiers, developing new products, and generating technological progress. STEM occupations are actively promoted by many federal agencies, such as the National Science Foundation, and are viewed as having some of the best opportunities for job growth in the future (see e.g., National Research

Council, 2014). Currently, they make up more than 1 out of every 10 jobs in the United States and have wages that are approaching nearly twice the U.S. average (Jones, 2014). The U.S. government agencies confirm that the STEM capital plays a crucial role in economic development of the United States (see, e.g., BLS, 2014; National Science Board, 2003; National Science Foundation, 2016; National Science and Technology Council, 2000; U.S. Department of Education, 2007; United States Government Accountability Office, 2014).

In this background, the study suggests two strategies to secure STEM workers. First, this study exhibits the required knowledge and skills for STEM students by analyzing O*NET data. Second, the study finds the factors, which are associated with the proportion of STEM workers, to promote STEM environments. To be specific, this study provides a deeper conceptualization of the knowledge and skills to be learned for STEM students by highlighting the required knowledge and skills for each STEM field. This study finds that the required knowledge and skills are differentiated by each STEM field, meaning that STEM policy planners need to respectively design the school and university curriculums based on the importance of knowledge and skill in each STEM. By doing so, students can develop a broad range of skills, including cognitive and meta-cognitive skills (e.g. critical thinking, creative thinking, learning to learn and self-regulation); social and emotional skills (e.g. empathy, self-efficacy and collaboration); and practical and physical skills (e.g. using new information and communication technology devices) (see OECD, 2018). This analysis plays an important role in promoting the aims and goals of the U.S. government because, to achieve their full potential as STEM workers, students need to develop a range of skills and knowledge that facilitate mastery and application of subjects, and business and political leaders are increasingly asking schools to develop skills such as problem solving, critical thinking, communication, collaboration, and self-management—often referred to as 21st century skills (National Research Council, 2012).

After the panel analysis, science and technology service has the highest positive elasticity on the proportion of STEM workers, and manufacturing shows the highest negative elasticity on it among all variables. The home value is the next negative variable, whereas foreign-born people have a positive impact on the gradient of STEM workers. In other words, the most powerful variables that affect the proportion of STEM workers in states are the industrial structure, followed by the house value, and foreign-born people. The study provides some important implications as follows: first of all, changing industrial structure is important to bring STEM workers into a region. In other words, governments should transform manufacturing-dominated industries into science and technology service-centered industries to attract STEM workers. Secondly, the government should stabilize the housing environment to bring more STEM workers into their region. Housing costs are one of the biggest expenses in people's life, and the costs can burden the STEM people. Lastly, the tolerance and openness in regions may be one of the important factors for bringing STEM workers in those regions. Therefore, local governments need to develop open and tolerant environments to attract more STEM workers into their regions.

The study examines the required knowledge and skills in the STEM fields and the factors affecting the gradient of STEM workers to help state and national education policies develop the various pathways that students continue to grow as a talented STEM worker. The implications can remove the barriers to STEM entry, provide systematic education curriculum related to the required knowledge and skills, and contribute to fostering competitive STEM workers (see National Academies of Sciences, Engineering, and Medicine, 2016). Also, the study would contribute to the influx of STEM workers into the states by analyzing the determinants of gradients in the proportion of STEM workers and provide some valuable implications for STEM Ecosystems by building ecosystem tools for comprehensive planning strategies on the state level. For example, the STEM Ecosystem organizations pursue to find the knowledge and skills required in STEM-related occupations and professions and to develop regional STEM alliance planning tools, and this study provides them by analyzing the STEM occupations in O*NET data and a variety of information of STEM workers in each state. The 21st century is the era of science and technology, and the STEM workers would be the main drivers to the prosperous future.

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References

Atkinson, R. D., Hugo, J., Lundgren, D., Shapiro, M. J., & Thomas, J. (2007). Addressing the STEM Challenge by Expanding Specialty Math and Science High Schools. *NCSSSMST Journal*, 12(2), 14-23.

Bailey, M. J. (1959). Note on the economics of residential zoning and urban renewal. *Land Economics,* 35(3), 288-292.

Blickenstaff, J, C. (2005). Women and science careers: leaky pipeline or gender filter? *Gender and education,* 17(4): 369-386. BLS. (2014). Stem 101: intro to tomorrow's job. Available at: http://www.bls.gov/careeroutlook/2014/spring/art01.pdf

Business Roundtable. (2005). *Tapping America's potential: the education for innovation initiative.* Business Roundtable, Washington, DC.

Bybee, R. W., & Fuchs, B. (2006). Preparing the 21st century workforce: A new reform in science and technology education. *Journal of Research in Science Teaching,* 43(4), 349-352.

Chen, X. (2009). *Students Who Study Science, Technology, Engineering, and Mathematics (STEM) in Postsecondary Education. Stats in Brief. NCES 2009-161*. National Center for Education Statistics, Washington, DC.

Clark, J, V. (1999). *Minorities in science and math. ERIC clearinghouse for science, mathematics, and environmental education*. Columbus, OH.

Cole, D., & Espinoza, A. (2008). Examining the academic success of Latino students in science technology engineering and mathematics (STEM) majors. *Journal of College Student Development,* 49(4), 285-300.

Congressional Research Service. (2008). Science, technology, engineering, and mathematics (stem) education: background, federal policy, and legislative action. *Congressional Research Service Reports* 35, 1-35.

Cover, B., Jones, J. I., & Watson, A. (2011). Science, technology, engineering, and mathematics (STEM) occupations: a visual essay. *Monthly Labor Review,* 134(5), 3-15.

Dickman, A., Schwabe, A., Schmidt, J., & Henken, R. (2009). *Preparing the Future Workforce: Science, Technology, Engineering and Math (STEM) Policy in K-12 Education*. Public Policy Forum, Milwaukee, WI.

Epstein, D., & Miller, R, T. (2011). *Slow off the mark elementary school teachers and the crisis in science, technology, engineering, and math*. Education Center for American Progress, Washington, D.C.

Florida, R. (2014). *The Rise of the Creative Class--Revisited: Revised and Expanded*. New York: Basic books.

Glaeser, E. L., & Shapiro, J. M. (2003). Urban growth in the 1990s: Is city living back? *Journal of Regional Science,* 43(1), 139-165.

Green, M. (2007). *Science and engineering degrees: 1966-2004 (NSF 07-307).* National Science Foundation, Arlington, VA.

Jones, J. I. (2014). *An Overview of Employment and Wages in Science, Technology, Engineering and Math (STEM) Groups*. Bureau of Labor Statistics, Washington, DC.

Kuenzi, J., Matthews, C., & Mangan, B. (2006). *Science, technology, engineering, and mathematics (stem) education issues and legislative options*. Congressional Research Service, Washington, DC.

Langdon, D., Mckittrick, G., Beede, D., Khan, B., & Doms, M. (2011). Stem: good jobs and now and for the future. *U.S. Department of Commerce 03(11*), 1-10.

Maton, K. I., & Hrabowski III, F. A. (2004). Increasing the Number of African American PhDs in the Sciences and Engineering A Strengths-Based Approach. *American Psychologist,* 59(6), 547.

May, G. S., & Chubin, D. E. (2003). A retrospective on undergraduate engineering success for underrepresented minority students. *Journal of Engineering Education,* 92(1), 27-39.

Milgram, D. (2011). How to recruit women and girls to the science, technology, engineering, and math (STEM) classroom. *Technology and Engineering Teacher*, 71(3), 4-11.

Miyake, A., Kost-Smith, L. E., Finkelstein, N. D., Pollock, S. J., Cohen, G. L., & Ito, T. A. (2010). Reducing the gender achievement gap in college science: A classroom study of values affirmation. *Science* 330(6008), 1234-1237.

Modi, K., Schoenberg, J., & Salmond, K. (2012). *Generation STEM: What girls say about science, technology, engineering, and math*. A Report from the Girl Scout Research Institute. New York, NY.

Morrison, T., Maciejewski, B., Giffi, C., DeRocco, E. S., McNelly, J., & Carrick, G. (2011). *Boiling point? The skills gap in US manufacturing*. Deloitte and The Manufacturing Institute.

National Academies of Sciences, Engineering, and Medicine. (2016). *Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Diverse Student Pathways*. Washington, DC.

National Governors Association. (2007). *Building a science, technology, engineering and math agenda*. National Science Board, Washington, DC.

National Governors Association. (2011). *Building a science, technology, engineering, and math education agenda*. Available at: http://www.nga.org/files/live/sites/NGA/files/pdf/1112stemguide.pdf

National Research Council. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: The National Academies Press.

National Research Council. (2012). *Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century*. Washington, DC: The National Academies Press.

National Research Council. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.

National Research Council. (2015). *Identifying and Supporting Productive STEM Programs in Out-of-School Settings*. Washington, DC: The National Academies Press.

National Science and Technology Council. (2000). *Ensuring a strong U.S. scientific, technical, and engineering workforce in the 21st century*. National Science and Technology Council Washington, DC.

National Science and Technology Council. (2013). *Federal science, technology, engineering, and mathematics (stem) education 5-year strategic plan*. National Science and Technology Council, Washington, D.C.

National Science Board. (2003). *The science and engineering workforce: realizing America's potential.* National Science Board, Arlington, VA.

National Science Foundation. (2016). *Science and engineering indicators*. National Science Board Arlington, Virginia, VA.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

OECD. (2018). *The future of education and skills education 2030*. OECD publication.

Price-Spratlen, T., & Guest, A. M. (2002). Race and population change: a longitudinal look at Cleveland neighborhoods. *Sociological Forum,* 17 (1), 105-136.

Shapiro, J. M. (2006). Smart cities: quality of life, productivity, and the growth effects of human capital. *The Review of Economics and Statistics,* 88(2), 324-335.

Simon, C. J., & Nardinelli, C. (2002). Human capital and the rise of American cities, 1900–1990. *Regional Science and Urban Economics,* 32(1), 59-96.

Slovacek, S. P., Whittinghill, J. C., Tucker, S., Peterfreund, A. R., Rath, K. A., Kuehn, G. D., & Reinke, Y. G. (2011). Minority students severely underrepresented in science, technology engineering and math. *Journal of STEM Education: Innovations and Research*, 12(1/2), 5-16.

Smeding, A. (2012). Women in science, technology, engineering, and mathematics (STEM): An investigation of their implicit gender stereotypes and stereotypes' connectedness to math performance. *Sex roles*, 67(11-12), 617-629.

Stout, J. G., Dasgupta, N., Hunsinger, M., & McManus, M. A. (2011). STEMing the tide: using ingroup experts to inoculate women's self-concept in science, technology, engineering, and mathematics (STEM). *Journal of Personality and Social Psychology*, 100(2), 255-270.

Tyson, W., Lee, R., Borman, K. M., & Hanson, M. A. (2007). Science, technology, engineering, and mathematics (STEM) pathways: High school science and math coursework and postsecondary degree attainment. *Journal of Education for Students Placed at Risk,* 12(3), 243-270.

Wingenbach, S. H., Degenhart, G. J., Lindner, K. E., Dooley, J. R., Mowen, D. L., & Johnson, L. (2007). Middle school students' attitudes toward pursuing careers in science, technology, engineering, and math. *NACTA Journal*, 51(1), 52-59.

Xue, Y., & Larson, R. C. (2015). Stem crisis or stem surplus: yes and yes. *Monthly Lab*, 138, 1-19.

U.S. Department of Education. (2007). *Report of the academic competitiveness of council, U.S. Department of Education,* Washington, D.C.

United States Government Accountability office. (2014). *Science, technology, engineering, and mathematics education assessing the relationship between education and workforce.* United States Government Accountability Office, Washington D.C.

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