A Pilot Study Investigating College Students Majoring in STEM: A System Dynamic Approach

Yi-Ching Lin, M.S.
Old Dominion University
Norfolk, Virginia
yxlin001@odu.edu

Ginger Watson, Ph.D.
Old Dominion University
Norfolk, Virginia
gswatson@odu.edu

ABSTRACT

Since 2006, Congress has stressed the importance of increasing Science Technology Engineering and Mathematic (STEM) majors to meet 21st Century workforce demands (Hanushek, Peterson,& Woessmann, 2012; Carnevale, Smith, & Melton, 2011). While previous studies have analyzed the relationship among factors that influence student's choice of a STEM major (Wang, 2012; Lent et al, 2005), no studies have used a grounded theory approach to develop a theoretical model. One of the benefits of using grounded theory is that the model can explain not only "what" influence students' choices of a STEM major but also "why." The primary data source for this pilot study was an individual, 30-45 minute, semi-structured, face-to-face interview with six undergraduate college students majoring in STEM fields recruited from the same undergraduate STEM Education and Professional Studies course. The semi-structured interview asked questions about participants' experiences choosing their majors. At the end of the interview, data were transcribed and e-mailed to students for member checking. Results indicate emergence of six domains to explain choice of major: interest in STEM, workforce demand, academic support, early environment, self-achievement, and social support. Trends for the choice of majors are presented along with the design of an initial model. Further development of this model will include a system dynamic simulation for educators and policy makers to estimate how specific strategies change the number of students majoring in STEM.

ABOUT THE AUTHORS

Ms. Yi-Ching Lin is a Modeling and Simulation Fellowship recipient at Old Dominion University where she is currently in her second year of coursework in the Ph.D. program in Occupational and Technical Studies in the STEM Education and Professional Studies Department. She holds a Master of Science degree in Psychology from Virginia State, a Bachelor of Science degree in Psychology from University of Missouri Columbia, and a Bachelor of Science degree in Chemical Engineering from the National Taipei University of Technology. Her current research centers on the use of systems dynamic modeling to assess the influence of various factors on students' choice of STEM majors.

Dr. Ginger S. Watson is Interim Chair and Associate Professor in the Department of Science, Technology, Engineering, & Mathematics Education (STEM) and Professional Studies in the Darden College of Education with a joint appointment at the Virginia Modeling, Analysis, and Simulation Center (VMASC) at Old Dominion University. She completed her Ph.D. in Instructional Design & Technology at the University of Iowa during where she received a number of awards including a Link Foundation Fellowship in Advanced Simulation and Training. She has almost 25 years experience in simulator design, development, validation and use including 15 years in senior and chief scientist positions. Her research interests include performance, cognition, and learning in simulation, gaming, and virtual environments. The backbone of this research is the use of physiological measures to assess attention, immersion, and cognition.

A Pilot Study Investigating College Students Majoring in STEM: A System Dynamic Approach

Yi-Ching Lin, M.S.
Old Dominion University
Norfolk, Virginia
yxlin001@odu.edu

Ginger Watson, Ph.D.
Old Dominion University
Norfolk, Virginia
gswatson@odu.edu

INTRODUCTION

Many researchers express concern about the decline of STEM (Science, Technology, Engineering, and Mathematics) candidates in the U.S. educational system and the impact this may have on the U.S economy in the future (Maltese & Tai, 2010; Fox & Heckerman, 2003). The increasing demands for a STEM workface continues to gain attention in the U.S. (Carnevale, Smith, & Stohl, 2013). Many undergraduate students majoring in STEM fields struggle to complete their degree in four years and often chose to leave STEM majors before they graduate with those degrees. Nearly twenty two percent of these students dropped out after five years (Boundaoui, 2011). In addition, the Bureau of Labor Statistics projects that with newly created jobs and the retirement of baby-boomers, there will be more than 3 millions STEM jobs by 2018 (Lacy & Wright, 2009; Maltese & Tai, 2011). The decline of STEM candidates is likely to result in a shortage of a STEM-educated domestic labor force to meet the demand, causing the US to lose competitiveness in STEM-related fields (Kelic & Zagnoel, 2009).

In previous studies, researchers primarily used self-report surveys to explain factors for predicting students who choose STEM majors. However, the resulting models are not able to interpret causal relationships among factors (Wang, 2013). In addition, human behavior is often a complex *nonlinear* and *dynamic system* making it more difficult for researchers to theorize and model this social behavior (Carley, 2001). Unlike previous studies that relied on quantitative self-report survey approaches and linear multiple regression or structure equation model for building theoretical model for studying students choosing STEM majors, the present study combined qualitative grounded theory research and system dynamic simulation to study the process by which students' choose a STEM major.

PREVIOUS RESEARCH

Social Cognitive Career Theory Predict Students Choosing STEM majors

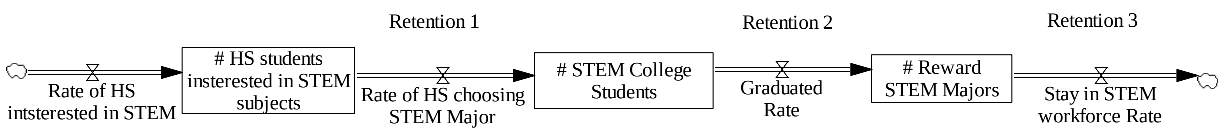
Social cognitive career theory (SCCT) is built upon Bandera's general social cognitive theory (1986, 1997) which explains how an individual's academic and career-related interests are influenced by the interaction of personal, environmental, and behavioral variables (Lent et al., 2005). The central mechanism of self-efficacy is based on an individual's beliefs about their capabilities to control events. Self-efficacy determines human motivation, affect, and action, and is the best predictor of students' ability to attain academic milestones and performance (Lent et al., 2005). According to Bandura's definition of self-efficacy (1997), students' confidence in their ability to successfully perform a variety of academic tasks including academic performance, persistence, perceived career options, coping with barriers, and solving problem in science and engineering majors (Lent et al., 2005). Lent et al. used quantitative self-assessment survey and structural equation model approach to develop theories explaining what influences students choosing STEM majors. They concluded that the most important factors in predicting students' choice of STEM majors are students' self-efficacy, technical interests, and social barriers. Their model also showed significant differences for gender and race (Lent et al, 2005). Although SCCT is a validated and widely accepted framework for studying topics such as the influence of students choosing an undergraduate major, few studies have demonstrated cross-sectional designs to investigate student pursuing a STEM major from secondary education carrying into postsecondary education.

Wang's (2013) social cognitive career theory is a modified theory based on SCCT (Lent, 2005). Researchers added several factors and used longitudinal study to investigate students choosing STEM major from 10th grade to college. This study reveals a number of important finding. First, high school parathion in math and science plays a critical role on students interested in pursuing and entrancing into STEM majors. Second, students' math self-efficacy beliefs, exposure to math and science, and completion in math and science courses significantly predict their intent to major in STEM fields as expressed during high school. Third, both students' intent to major in a STEM field and the completion of math and science courses significantly predicts students' entrance into STEM majors in college (Wang, 2013). Although Wang (2013) provided a more comprehensive framework for explaining students' choosing STEM majors than Lent (2005), there is no basis for estimating causal relationships among the factors in either study thus limiting the ability of these studies to project the number of students choosing STEM major in the future.

Limitations of Existing Research

In order to capture dynamic changes associated with students choosing STEM majors from secondary education to post-secondary education, Wang (2013) analyzed the longitudinal process. A full picture of this process helps researchers and educators to better understand how the two institutional levels shape students' entrance into STEM (Wang, 2013). However, use of these traditional statistics methods limits the ability to project the number of students entering the STEM major. The benefit of using system dynamic simulation instead of regression-based methods is that projections can be made to estimate the number of student in STEM pipeline. Such an approach could provide educators and policy-makers with a tool to estimate and assess policies and strategies for increasing the number of students choosing STEM majors (see Figure 1).

Figure 1. STEM Students' Career Pipeline – System Dynamic Simulation

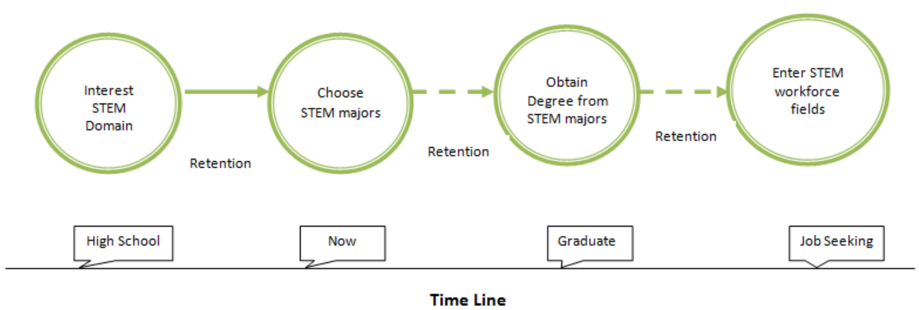


While system dynamic researchers and computational modelers can use existing quantitative or qualitative theoretical models to build a system dynamic simulation, many modelers find that using an empirically-based, qualitative grounded theory research design provides more depth and rich detail for modelers to build more concrete and robust simulations (Carley, 2001). Unfortunately, no studies have used such a qualitative research approach to investigate the causal relationships among factors influencing students choosing STEM majors. In the present study researchers use qualitative, grounded theory to develop a model explaining the process that students use when choosing STEM majors.

Current stage of present study

The present study investigated the factors that influenced student's interest in STEM majors in high school and how these factors impacted students' decision to declare a STEM majors in college. Researchers used a grounded theory approach to develop a theoretical model to explain the factors influencing students choosing STEM majors in the present stage (See Figure 2). The benefits of using grounded theory were that (1) the model was able to explain "what" and "why" influence students choose STEM majors, and (2) researchers could develop the causal-effect relationships among factors for developing a system dynamic simulation later on.

Figure 2. STEM Students' Career Pipeline



Purpose and conceptual framework

The purpose of the current study was to determine the factors and process that students use when choosing a undergraduate STEM major. The study used a grounded theory and post-positivism research paradigm approach. Development of a ground theory model involves systematically analyzing and generating a phenomenon inductively to explain how the process occurs (Strauss & Corbin, 1998; Glaser & Straus, 1967). Post-positivism assumes that reality or universal truths really exist and emphasizes methods to pose, document, and test validity, reliability and alternative hypotheses throughout the research process. The present study utilized a series of philosophies of science based in grounded theory tradition and a post-positivism research paradigms. Ontologically findings approximated truth and the final model was built on participants' perspectives regarding their high school and college experiences in order to understand the mechanism of college students' choosing a STEM major. Epistemologically, knowledge was obtained through measureable experiences with each participant drawn directly though face-to-face interviews. Axiologically, researchers had minimal influences on the results and remained emotionally neutral during the interview.

METHDOLOGY

Participants and Context

Six undergraduate students who had either decided or declared their majors in STEM fields were interviewed for this study. Participants were recruited via the same course in the Department of STEM Education & Professional Studies at Old Dominion University and were offered extra credit for their participation. Participants included five females and one male. Two were African American and four were Caucasian. The overall mean age of the sample was twenty-two years. The sample included one student from each of the following majors: biology, mathematic, chemistry, psychology, nursing, and dental hygiene. Old Dominion University enrolls approximately 25,000 students and 25 % students represent minority groups. This school has 69 bachelor, 54 master, and 42 doctoral degree programs. Overall, 80% of students are pursuing STEM majors.

The Definition of STEM Majors

The STEM-Designated Degree Program List was used to categorize participants' majors. The list was originally released by the Department of Homeland Security (DHS) in April 2008 and has made subsequent updates since that time (ICE, 2012).

Research Team

The first author conducted interviews, developed the initial coding framework, and used that framework to code data. The second author guided the methodology, verified the coding framework, and confirmed the resulting model.

Procedure

The primary source of data was individual, face-to-face interviews. Interested participants were contacted via e-mail where they were given a study information sheet explaining the purpose, details, and time commitments for the study. Interviews were scheduled with each participant. During the interview the researcher read an informed consent script articulating the study purposes, risks, benefits, and asking for approval to audio record the session. Participants were required to give verbal consent acknowledging their agreement to participate in the study and to be audio recorded during the interview. The semi-structured interview included demographic items and asked open-end questions regarding participants' experiences choosing their majors. Questions focused on experiences, opinions, knowledge, and feeling, as well as probing questions to solicit additional details. The researcher slightly adjusted the semi-structured interview questions between participants based on the responses in previous interviews in order to fully address the overarching study questions. This is a common practice and benefit to qualitative, semi-structured interviews. The interviews lasted approximately 30-45 minutes. At the end of the interview, data were transcribed and e-mailed to students for checking accuracy. To receive the full extra credit, participants needed to verify and return the transcript for analysis.

Data Analysis

Open coding was conducted after each interview. The initial codebook served as a framework for coding future transcripts. The unit of analysis for the initial set of codes was at the sentence level. Once open, coding was completed for each interview. The researcher used axial coding to relate formal concepts and categories across the datasets. Through ongoing coding processes and continuation of memoing, the researcher used selective coding to identify core categories and subcategories to develop the theoretical model. All theoretical code was derived using a relational model through which all substantive codes or subcategories were related to the main categories (domains) in the empirical data. One coder completed all coding for this plot study with 10-14 days between open code, axial code and selective code. During this process, the researcher immersed herself in the transcripts where she constantly checked the original transcripts to ensure accuracy in coding. The collaborating researcher reviewed the process and verified the emerging codes, subcategories, and the model at the sentence, code, category, and model levels.

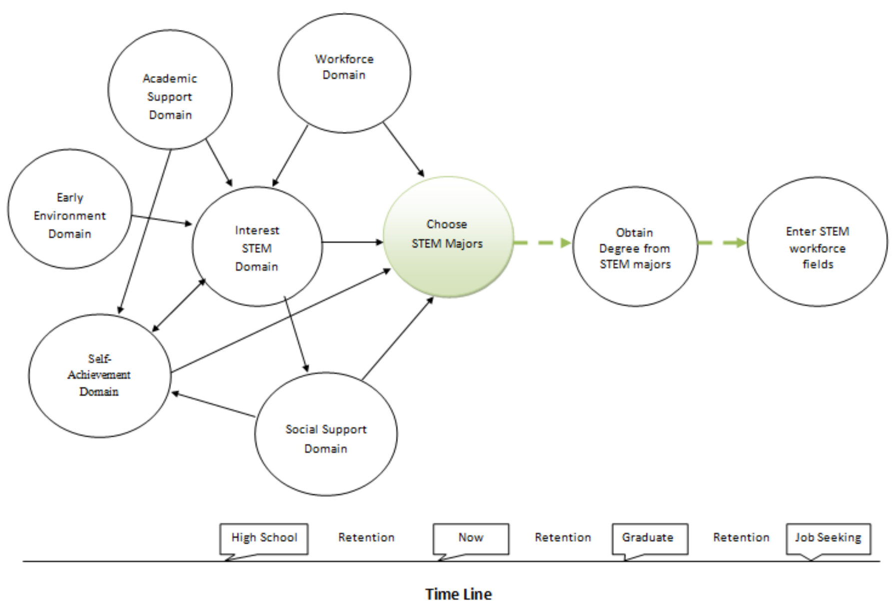
Strategies of Trustworthiness

Several strategies were utilized to increase trustworthiness for this study. First, member checking was used to verify that every transcript correctly reflected the individual participant's experiences. The researcher used memoing and thick description after each data collection to increase the reflexivity of the research. The process of constant comparison between the data sets was employed to increase reliability and validity. An auditory trail was created to provide physical evidence of systematic data collection and analysis procedures. In addition, the researchers utilized strict guideline of qualitative research traditions throughout the design and conduct of the study to ensure procedural rigor and coherence.

FINDINGS

The grounded theory model developed from this analysis is displayed in Figure 3. This theoretical model represents and explains the factors that influence college students who choose STEM majors. Pilot study results indicate six primary domains that influence college students choosing STEM majors: (1) interest in STEM, (2) workforce demand, (3) academic support, (4) self-achievement, (5) early environment, (6) social support domain (see Figure 3). Several subcategories also emerged for each domain (see Table 1). In this section, each of the categories (domains) is explained to illustrate how they interact and interrelate to tell the story of how each domain influences students when choosing to major in a STEM discipline.

Figure 3. Factors Influencing College Students Choosing STEM Majors



Interest in STEM Domain

Student's interests in STEM during high school directly influenced their choice when majoring in STEM disciplines in college. Student's interest in STEM was directly affected by their early environment, academic support, achievement, and workforce knowledge.

> ***Researcher:*** *I know you talked a little bit about your teachers. Did any teacher or instructor influence you to choose your career? How did they influence you?*
> ***John:*** *I had a math teacher who got me interested in math and it became sustainable. It lasted longer—until high school. That math teacher inspired me to take enjoyment from math.*

Teachers' academic and social support influenced John's interested in math in middle and high school. Jenny also reported how her early exposure to chemistry and physics in school and in her family directly influenced her interested in studying chemistry later on. Although early environment did not directly influence students when choosing STEM majors in college, the influence of early environment service as a key element to student's interested in STEM in high school. Having good performance in STEM subjects and clear career goals also directly influenced students choice. The researchers used positive and negative interview questions to clarify the reasons that they did or did not choose STEM majors. The results indicated that performance was a main factor when choosing a STEM or non-STEM major. Both academic and social support could strengthen their confidence in choosing a STEM major in college.

> ***Researcher:*** *When did you feel you were really good at math, and how did it influence your choice?*
> ***Joan:*** *In high school, I was ok at math. I liked it but was not so sure. But because I was good at math in community college, I went toward that. I am not so good at chemistry or biology or English, so I didn't want to do those.*

One of most influential domains impacting students' choice of a STEM major was workforce demand. Workforce demand not only influenced their prior choice but it continued to influence their current and future choices. This domain was comprised of three subcategories including workforce knowledge, job vacancy and wage. Surprisingly, many students reported their reasons for choosing a STEM major was the predominate job vacancies and associated wages.

> ***Researcher:*** *What were the primary reasons that you choose your current major?*
> ***Judy:*** *hmm, first, I know there is always going to be a need for nurses (**job vacancy**), and money **(wage)**, and always going to be able to **help people** (career goal).*

In summary, the model illustrated the factors and sequence of students' choosing STEM majors. Discovering the processes of how students choose STEM majors provides a rich understanding of the reasons students eventually choose to major in STEM and how these factors interplay to influence the final choice of college major.

DISCUSSION

First, the early environment domain played the critical role of influencing students' interested in STEM fields in high school. In some instance, participants reported their family environment or some early experiences rendered their interested in STEM fields initially or later on. Five of six participants reported that their early childhood experiences or family environment influenced their interested in STEM fields in high school, and indirectly influenced their choosing this major in college. Similarly, other studies have showed that students' exposure to math and science in high school was positively correlated with students' intent to major in a STEM field (Wang, 2013).

Second, workforce knowledge directly impact students' choices in both secondary education and postsecondary education. Especially, having contact with experts or people who are working in the fields in which students are interested could directly influence students' choice and persistence in pursuing this career after graduating from college. Third, teachers' and tutors' academic support directly influenced students' interests and students' achievement in choosing in STEM field. The self-achievement domain was closely allied with results by Wang (2013) and Lent et al. (2005). Students' math achievement (Wang, 2013) and expectations influenced students interest and intent to major in STEM fields in high school while eventually influencing students' entrance in STEM fields in college (Wang, 2013; Lent et al., 2005). Unlike Wang and Lent's studies which separated self—efficacy into different categories, the present study merged self-efficacy, achievement, career goal, and expectation of contribution to society into a single self-achievement domain. Finally, the social support domain did not directly influence students' interests as Lent' study indicates. The current study found that students showed their interests first and social supports reinforced students' choosing majors.

Limitations

The current study interviewed only six participants and thus has limited estimates of validity and reliability. The authors are continuing to collect data. In addition, the present study only had one coder. Researchers will utilize additional coders in future analyses.

Future Direction
The authors will investigate additional variables in the future to understand how factors such as ethnicity affect the present model and students' entrance into STEM majors and Non-STEM majors.

ACKNOWLEDGEMENTS

The authors thank Dr. Kimberly Baskette for her assistance with participants for this study. They also wish to thank Drs. John Sokolowski and Jose J. Padilla for their early discussions on using systems dynamic modeling for this work. Yi-Ching Lin would like to acknowledge the generous support of the Modeling and Simulation Graduate Research Fellowship provided by Old Dominion University during 2013–2014.

REFERENCES

Boundaoui, Assia (2011, May 21). Why would-be engineers end up as English majors. *CNN*. Retrieved from http://www.cnn.com/2011/US/05/17/education.stem.graduation/index.html

Bronfenbrenner, U, (1977). Toward an experimental ecology of human development, *American Psychologist, 32*, 513-531.

Carley, K. M. (2001). Computational approaches to sociological theorizing. *Handbook of sociological theory*, Springer: 69-83.

Lacey, T. A., & Wright, B. (2009). Occupational employment projections to 2018. *Monthly Labor Review, 132*(11), 82–123.

Lent, R. W., et al. (2005). Social Cognitive Predictors of Academic Interests and Goals in Engineering: Utility for Women and Students at Historically Black Universities. *Journal of Counseling Psychology 52*(1), 84-92.

Kelic, A. and A. Zagonel (). Science, technology, engineering, and mathematics (STEM) career attractiveness. Retrieved from http://www.systemdynamics.org/conferences/2009/proceed/papers/P1390.pdf

Maltese, A. V. and R. H. Tai (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among US students. *Science Education 95*(5), 877-907.

Merrick, E. N. (1995), Adolescent Childbearing as Career Choice: Perspective from an ecological context. *Journal of Counseling & Development, 73,* 288–295. doi: 10.1002/j.1556-6676.1995.tb01750.x

The Department of Homeland Security (2012). STEM-Designated Degree Program List. Retrieved from http://www.ice.gov/doclib/sevis/pdf/stem-list.pdf

Wang, X. (2013). "Why Students Choose STEM Majors: Motivation, High School Learning, and Postsecondary Context of Support. *American Educational Research Journal 50* (5), 1081-1121.

Table 1. The Coding Frame and Case Display of College Students Choosing STEM Majors

Category	**Subcategory**	**Definition**	**Example**
Early Environment Domain	Early life experience	Experiences influences decision (+,-)	Jenny: ..both middle and high schools I had science experiences
	Early family Environment	Parents jobs, interests etc. influences (+,-)	Jenny: we did a lot of [chemistry, physical] experiments at home.
Interest Domain	Interested in STEM fields	Interested in STEM fields influences choosing major	John: when I was in middle and high school, I loved science.
Self-Achievement Domain	STEM Subjects Performance	STEM subjects performance influence choosing major	Joan: Because I am good at math ..so I want toward that direction.
	Determination to face challenges	Determination to deal with STEM classes challenges	John: I would push myself to achieve that goal.
	Self-Efficacy	Believe having ability to handle STEM Subjects	Julia: I have more confidence…
	Career Goal	Having clear career goal influences choosing major	Jenny: My end goal is forensic anthropologist.
	Contributions to the Society	Expecting to have contributions to the society	Judy: …always going to be able to help people (being a nurse)
Academic Support Domain	STEM Teachers	Have good STEM teachers influence choosing major	Joan: I had some really good teachers. They really love math.
	Any academic resources	Any academic support you studying STEM subjects	Joan: Right now it has a lot of opportunities to get tutor…
Workforce Domain	Workforce knowledge	Knowing your major how to apply in future job	Jennifer: I went to the observation, career shadow
	Job vacancy	(Un)employment rate influences your choice (+,-)	Julia: it does influence my choice.
	Wage	How much wage influences choosing major	Judy: Wage influenced my decision a lot.
Social Support Domain	Family support	Family support your decision	Julia: They supported what I chose.
	Teachers support	Teachers support your decision	Jenny: my chemistry teacher really supports me.
	Adviser support	Advisers support your decision	John: I have great advisers and proved great information I need.
	Peers support	Peers support your decision (+,-)	Joan: We studied math together ..
	Experts (STEM fields) support	Experts support influences your choice	Jennifer: .the dentist.. tell me his opinions about working .
	Financial support	Have financial support influence your choice	Joan: ..I can be in STEM filed and go to college.