

RESEARCH REPORT

Beyond the Leaky Pipeline: Developmental Pathways That Lead College Students to Join or Return to STEM Majors

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Abstract: *STEM education researchers often invoke the “Leaky Pipeline” metaphor (National Research Council, 1986) when explaining why so many students do not persist in STEM. This metaphor envisions the supply of potential workers as a pipeline. Students “drip out” (leave STEM) of the pipeline from preschool through college. However, this metaphor does not adequately reflect the fluidity and multi-directionality of students’ decisions about their college majors. For example, some students join STEM after leaving another (non-STEM) major, and others add STEM as a second major. Increasing the number of students who join STEM could contribute substantially to addressing the STEM shortage. We used the term STEM joiners to refer to these students. We conducted a qualitative study of 22 college STEM joiners to explore the developmental trajectories and motivations of these STEM joiners. Data was collected through semi-structured clinical interviews with each individual and was analyzed by an iterative, grounded coding processes to derive themes and categories. We found that the decision to join STEM after declaring another major was often motivated by a desire to return to original interests in STEM. Early college STEM courses, supportive STEM environments, and mentoring experiences were critical in students’ joining decisions. The results suggest ways in which STEM joining could be increased, which could lead to an increase in the number of STEM majors.*

Keywords: *STEM education, development, higher education*

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Introduction

The U.S. needs many Science, technology, engineering, and mathematics (STEM) experts for both current and future jobs (Langdon et al., 2011; Peri et al., 2014). However, about half of bachelor's degree candidates in STEM end up leaving STEM fields by either changing majors to non-STEM fields or leaving postsecondary education without earning a degree in the U.S. (Chen & Soldner, 2013). Thus, the U.S. does not produce enough STEM majors to meet current demand, and the problem is likely only to get worse.

The attrition in STEM majors is viewed as a primary cause of the deficit in the supply of STEM workers in the U.S. Consequently, most research on this topic has assessed postsecondary students' leaving STEM fields at different stages, as well as high school students' decisions to enter STEM fields (Alper, 1993; Anderson & Kim, 2006; Astin & Astin, 1992; Chen, 2015; Green & Sanderson, 2018; Hall et al., 2011; Perez et al., 2014; Seymour, 2000; Wang, 2013; Xu, 2017).

The Leaky Pipeline Metaphor

In characterizing the causes of the STEM shortage, many researchers invoke the Leaky Pipeline Metaphor (National Research Council, 1986; See Figure 1 for an example). The entry pool of potential STEM workers is quite large at the elementary and middle school level, but many students lose interest in subsequent grades or stages and focus on other, non-STEM subjects. Thus, the number of students interested in STEM shrinks at all stages of education; the supply pipeline that leads to qualified STEM workers is therefore very leaky.

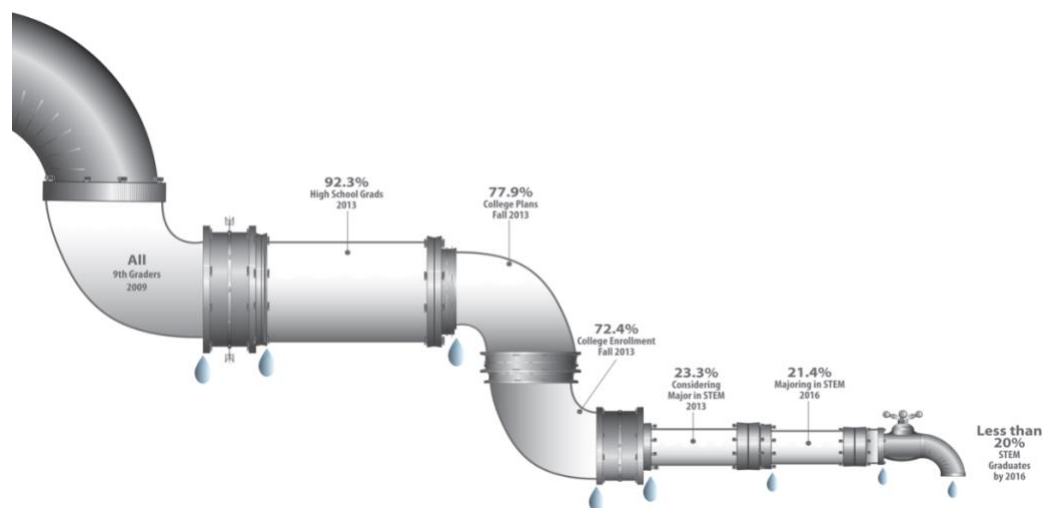


Figure 1. Leaky STEM Pipeline. Potential STEM workers drip out at every major transition point. Drawing by Lynn Pearson; copyright belongs to the authors. The data source is NCES HSLs:09 (National Center for Education Statistics, High School Longitudinal Study of 2009).

The pervasive leaky pipeline metaphor has greatly influenced how researchers and educators interpret and attempt to rectify the shortage of U.S. STEM workers. The Leaky Pipeline has, in fact, become a “metaphor we live by” (Lakoff and Johnson, 2008), structuring how we conceive of the STEM shortage and of possible solutions to it. For example, there is great emphasis on “patching” the pipeline—finding ways to keep people (particularly women and minorities) interested in STEM so they do not “leak” (e.g., Gasser & Shaffer, 2014; Minefee et al., 2018). Likewise, efforts to understand why women and minorities are underrepresented also focus either on leaks or lack of adequate supply from the beginning (Anderson & Kim, 2006).

Limitations and critiques of the leaky pipeline

The leaky pipeline metaphor has helped to frame and highlight the STEM shortage, but it has some important limitations. First, it implies that STEM fields are particularly leaky in comparison to other fields, but this may be an exaggeration. At least at the college level, STEM fields are only slightly more “leaky” than other fields (Chen & Soldner, 2013). For example, Leu (2017) reported that 35% of the students who originally declared STEM majors switched their majors during college, and that 29% of students who declared non-STEM majors also switched majors. Leu’s (2017) report was based on the Beginning Postsecondary Students Longitudinal Study (BPS: 12/14), a nationally representative study of about 25,000 students. “Leaking” (i.e., leaving a college major) is thus a common event, regardless of whether a student is a STEM or non-STEM major. Thus, it seems unlikely that differential levels of leaking are the primary cause of the STEM shortage.

The second important limitation of the leaky pipeline metaphor is “its emphasis on a neatly linear progression through a fixed set of benchmarks” and that “it diminishes variation in the motivation for pursuing STEM courses and the range of experiences they may offer” (Cannady et al., 2014, p. 448). The leaky pipeline metaphor is unidirectional; it focuses only on students who leave STEM and does not consider the possibility of students entering a STEM field after declaring other, non-STEM majors. However, unless they leave college or university entirely, students who leave one major usually declare another major. Thus, across the university, it is common for students to not only leave one major but also to join another (e.g., Lykkegaard & Ulriksen, 2019). Put simply, the leaky pipeline metaphor does not help us to frame the fluidity of students’ major selections.

Beyond the Leaky Pipeline Metaphor: Situating the Problem in a Developmental Context

The challenges to the leaky pipeline metaphor have led some scholars to consider alternatives and to view the STEM shortage issue in a broader, developmental context. Particularly in early adulthood, development often involves an iterative series of choices and the experience of their consequences, sometimes in the context and sometimes on self-identities. For

example, work in developmental psychology stresses the dynamic and at times unstable nature of students' emerging identities, as it is reflected in their college majors (Arnett, 2000; Arnett, 2004). For young adults who attend college or university, the selection of a major (or majors) is often very challenging, and they may change their minds frequently when they make important decisions. (Arnett, 2000; Arnett, 2004; Goldscheider & Goldscheider, 1999). The process of both selecting and completing a college major is thus not only about what one will study; it is also about committing to an identity (Erikson, 1968; Phinney & Alipuria, 1990). For many college students, the selection of a college major is the first step in choosing an occupation, and thus this decision is particularly important for the identity development process (e.g., Erikson, 1968; Grotevant et al., 1986; Lent, et al., 1994; Seginer & Noyman, 2005; Skorikov & Vondracek, 1998). Therefore, students' educational choices become central to their future employment and the formation of a career identity (Arnett, 2004; Creed & Hughes, 2013; Lehmann & Konstam, 2011).

The challenges of choosing a major may be particularly strong in the U.S. because students can easily change majors. In contrast to many other countries that have more restricted policies on students' major declaration (e.g., China, South Korea, Switzerland), students at many four-year American colleges or universities can take up to two years before declaring a major. Moreover, they often still can also easily change their minds after declaring one major and switch to or add another. In combination, these characteristics of the American higher education system mean that students have time to think about and try out different majors. Thus, many American students change majors at least once, and sometimes multiple times (e.g., Arnett, 2004; Arnett, 2016; Cheah & Nelson, 2004; Creed & Hughes, 2013; Lehmann & Konstam, 2011; Nelson & Padilla-Walker, 2013; Tanner, 2006), depending on how flexible the universities' major declaration policies are.

Although STEM and non-STEM majors both change majors (or add a second major), most research focuses only on those who leave STEM fields to join non-STEM fields. We know much less about movement in the opposite direction: entering a STEM major after beginning in one of the non-STEM fields. In fact, there is possibly an often overlooked group of STEM joiners—individuals who come to STEM after leaving another major, or who add STEM as a second major after initially declaring a non-STEM major, or who declare a STEM after remaining undecided during the first or two college years. For example, in an analysis of the more recent Beginning Postsecondary Students Longitudinal Study (BPS: 04/09) data set, (Wine et al., 2011). Miller (2018) found that 23% STEM graduates entered STEM from the “undecided” category and another 18% of STEM graduates entered STEM from non-STEM majors. Thus, up to 41% of STEM degree holders in the BPS: 04/09 dataset were not initially majoring in STEM when they first started college.

The existence and frequency of joining STEM from either another major or from undecided raises a new and potentially fruitful way to address the STEM shortage: increasing the number of students who join STEM. Increasing the rate of STEM joining might be as or more effective than increasing persistence (aka preventing leaks in the pipeline). Thus far, most work has focused on preventing pipeline leaks, but our analysis indicates that broadening the conceptualization of possible solutions to include STEM joining may also help to redress the problem. In fact, increasing STEM joining rate by just 5% might potentially produce 63,000 more STEM graduates per year (Miller, 2018).

In summary, to understand the STEM shortage, and to begin to redress it, we should extend our conceptualization beyond the leaky pipeline metaphor. STEM joining and STEM leaving are both part of a larger developmental process. The selection and re-selection of a college major is part of a dynamic, developmental system. Therefore, we should consider movement in both directions, both out of STEM and into STEM, because students often change majors as they develop their personal and professional identities.

Current Research

Thus far, most studies of STEM joining have been based on large-scale surveys (e.g., Cannady et al., 2014; Lykkegaard & Ulriksen, 2019; Mervis, 2014; Miller, 2018). These studies provide information about the existence of STEM joining and its possible importance. However, prior survey studies may not provide the kind of detailed information that is needed for faculty, administrators, and peer mentors to find ways to increase the number of STEM joiners. Although many studies have examined STEM “leaking”, there has been substantially less research on STEM joining. We suggest that we need research on both STEM “leaking” and STEM joining to address the STEM shortage effectively. Here we sought to complement and extend the few studies of STEM joining that have been conducted (Cannady et al., 2014; Lykkegaard & Ulriksen, 2019; Mervis, 2014; Miller, 2018). We augment prior large-scale, correlational studies of STEM joining with a detailed, qualitative study of the characteristics of STEM joiners. A more focused and detailed analysis of the characteristics and pathways of STEM joiners is needed to understand their motivations for joining STEM and the developmental pathways that led them there. This approach is complementary to the surveys; it will give us a broader (and more accurate) perspective on the process of becoming a STEM major and will also highlight new ways to increase the number of STEM majors and graduates.

The primary goals of this research therefore are to understand the motivation of STEM joiners, to sketch out the developmental pathways of STEM joiners, and to analyze the narratives that students construct about these developmental changes. Specifically, our research questions include:

- a) When did the students join STEM?
- b) What were they studying before they joined STEM?
- c) Why did they join STEM?
- d) What were the developmental pathways that led them there?

We argue that the decisions to join STEM must be viewed in a broader context that traces back to years before college to better understand students' changes and development. We addressed the motivation of STEM joining by not only focusing on some critical events that affected STEM joiners' decisions to join STEM fields, but also paying attention to critical people involved in the critical events. Considering these events and influence of critical people could illuminate some interesting narratives and help us mapping out the developmental trajectories.

Method

Approach

To achieve our goals of uncovering the characteristics of STEM joiners and understanding their motivations and pathways, we took a qualitative approach and conducted in-depth interviews on a group of students to learn about their personal stories. Qualitative scientific research methods can provide thick descriptions (Geertz, 1977) of people and contexts, inform the development of theories (Sofaer, 1999). Qualitative methods can be construed as a complement to quantitative methods; the qualitative methods provide very detailed information about a relatively small number of participants, whereas quantitative studies typically provide less detailed information about a much larger number of participants.

Participants

Operationalizing STEM joining

We defined STEM joiners as individuals who did not start college as a STEM major but added a STEM major sometime in college. This definition could include students who switched from a non-STEM major to a STEM major as well as students who added a second, STEM major while keeping their original non-STEM major. Our definition of "STEM majors" follows the National Center for Education Statistics' classification of STEM fields, which mathematics, physical sciences, biological/life sciences, computer and information sciences, engineering and engineering technologies, and science technologies, but excluded social sciences and health/nursing (Chen & Soldner, 2013).

To recruit STEM joiners, we sent emails to faculty who, were teaching an introductory STEM class when we collected data in one of the following topics: Chemistry, Physics, Biology, Computer Science, Math, and Engineering. After obtaining IRB approval, we emailed the instructors, asking them to forward our recruitment information to the students in their classes.

We also contacted STEM departmental staff through departmental online directories, asking them to send project information to their undergraduate mailing list. We invited students from several private and public universities in the Midwest and in the South, as well as liberal arts colleges in the Midwest to participate.

We recruited a total of 22 undergraduate students (11 males and 11 females) ranging from second year to fourth year who met the criteria of STEM joiner as described above. 17 of the STEM joiners attended an elite private university in the Midwest, 4 attended liberal arts colleges in the Midwest, and 1 attended a regional state university in the South. The liberal arts colleges have the most flexible major declaration policies that students could remain undeclared till the end of their second year. The rest of the institutions also have relatively flexible major declaration policies that students may have up until their third year to finally settle down on their major(s). Participation was voluntary, and we compensated students with either \$10 cash or a \$10 Amazon gift card.

Materials

We developed a semi-structured interview protocol (see Appendix A for details) to assess several themes relating to a student's choice of major, career aspirations, and identity formation. The interview protocol was informed by prior research on STEM "leaking" (e.g., Seymour, 2000) and was developed to maintain openness that could potentially lead to some interesting conversations. The semi-structured approach gave us flexibility to invite respondents to expand on specific comments and allowed us to ask tailored questions that helped to uncover students' narratives regarding their decisions to join STEM.

The interview had four sections; examples of questions are given in Appendix A. The four sections were designed to answer the research questions posed above: a) When did the students join STEM? b) What were they studying before they joined STEM? c) Why did they join STEM? and d) What were the developmental pathways that led them there? The first section was demographic information; we asked each student his or her major, year in school, and when he or she joined STEM. This section allowed us to tap into our first two research questions around students' time of joining and their previous majors. The second section was pre-college experiences, which included questions about students' memories of their career aspirations when they were younger, and their impressions of STEM when they were in high school. This section was designed to discuss prior experiences of the students and uncover traces on why these students did not start with a STEM major in college. The third section, decision process, asked about college major and career identity formation. We asked students about their decision to join STEM and whether the respondents had taken any STEM courses before they joined STEM. If they had, we asked them to elaborate on their STEM course experiences. We also asked them to think about whether a specific person, such as professor, teaching assistant, or parent, played an

important role in the decision process. This section was the major focus of our interview protocol, and we sought to awaken students' memories by asking them to reflect on some critical events or critical people. The final section, comparing STEM and Non-STEM courses, asked students to think about the difficulty of studying STEM subjects versus studying non-STEM subjects. This section allowed us to compare students' impressions on both STEM and non-STEM as well as to potentially understand why they picked one over another.

Although we prepared some questions prior to conducting our interviews, the protocol was not rigid; we continuously refined and augmented the questions according to participants' responses. We attempted to maintain a natural flow to the conversations rather than rigidly following the interview structure. We always pursued new issues that participants mentioned that were pertinent to their joining. For example, one participant mentioned that his parents were both immigrants with strong scientific backgrounds. We treated this as an indicator relevant to our conversation and elicited more information on this topic to find out what specific influence the parents had on his decision to study a certain major. This iterative strategy allowed us to cover as many possible factors that affected students' decisions to join STEM as possible, and therefore led us to a more comprehensive understanding of STEM joiners.

Procedure

Participants first provided informed consent. Some interviews were conducted in-person where possible, while some were conducted remotely via Skype. Interviews were conducted on a one-on-one basis, and each interview lasted about an hour. We took notes during the conversations and recorded the audio using a high-quality portable recorder. All the interviews were later transcribed verbatim, with the assistance of version 2.2.3 of the transcription software InqScribe (2015) or through a professional transcription service.

Analysis

The first author conducted an iterative inductive coding process, and both authors were involved in the discussion of organizing and summarizing elements from the coding into richer developmental pathways.

Inductive coding

We began with a bottom-up, grounded, inductive coding (e.g., Bryman & Burgess, 2002; Miles, et al., 2013; Strauss & Corbin, 1997). Inductive coding was the best way of realizing our goal as it allowed for open and unrestricted analysis of our data. This inductive coding had two phases. The first was an in vivo coding (Miles et. al., 2013), in which we read through the transcripts several times and focused participants' own words to begin to identify themes and categories. Phrases that are used repeatedly by participants are often good leads, and this method prioritizes and honors the participants' voice. For example, the code "not a STEM person in high

school” came directly from our participants’ words; we noticed that several students said they didn’t think they were talented in STEM in high school. This strategy of using the respondents’ own words as codes sheds light on what the individual respondent thought were important aspect of his or her own journey of joining STEM. Moreover, in vivo coding allowed for a close look at students’ change in selves and affect at the moment. Also, because we only asked probing questions and most of the points were brought up by the interviewee him or herself, in vivo coding could potentially capture the most striking points related to our inquiry without being constrained by our prior knowledge.

Our second inductive method was a descriptive coding (Miles et. al., 2013) strategy, in which we began to summarize students’ responses and capture the decision factors of joining STEM. The purpose of the descriptive coding was to move beyond very specific moments and an exclusive focus on interviewee’s own words to a somewhat more general (and less granular) description. For example, our in vivo coding revealed many responses that referred to mentoring in some way. We therefore developed codes of “mentoring from professors” and “mentoring from TA/graduate students” to capture those responses. Likewise, we developed a code of “career consideration” to capture responses in which students talked about their future career planning when deciding whether to join STEM. These descriptive codes eventually could provide an inventory of topics for further indexing and organizing. Taken together, the two inductive and convergent coding approaches allowed us to address the factors that influenced STEM joining at both macro and micro levels, while simultaneously facilitating the development of a succinct, accessible coding system. Appendix B is the inductive coding system.

The processes of defining and identifying themes were iterative (Miles et. al., 2013). We continued refining our coding system as new themes emerged, until no more new themes emerged, which suggested that we had identified main themes. After the coding system was developed, we reviewed and discussed all the transcripts again to ensure that all the decision factors of STEM joining were coded.

Describing students’ trajectories

The codings described thus far helped us to understand the key events or experiences that students mentioned in their interviews. Our next step was to organize these key events and experiences into coherent developmental trajectories. Students’ descriptions of these events often included not only the event itself (e.g., “I took a [computer science course] in the fall”), but also a description of associated feelings and beliefs (e.g., “I had a really good time with it. It felt very comfortable to join the major after that.”) The stories that students shared integrated events and belief changes across several years, usually from the middle or high school through the middle years of college. For example, the code “dreams and goals related to STEM” would fall under the category of “initial interest in STEM”, while the codes “supportive STEM environment” and

“mentoring from professors” would both fall under the category of “join (or return to) STEM”. These trajectories were derived from our interpretation and organization of the codes shown in Appendix B.

In summary, our analysis relied both on coding specific elements of the individual interviews and on summarizing these elements into richer developmental pathways. This multi-step inductive approach provided us a thorough analysis of STEM joiners’ memories of and interpretation of their developmental pathways.

Results

Our analyses of the interviews addressed four general questions: a) When did the students join STEM? b) What were they studying before they joined STEM? c) Why did they join STEM? and d) What were the developmental pathways that led them there? The last two questions are the most intensive and address the central questions regarding the motivation for and pathways to STEM joining.

When Did They Join STEM?

To better understand joining STEM in a developmental context, it is important to find out when students joined STEM. Our interviews revealed that most students joined STEM during their first or second year in college. All but 3 of the 22 respondents joined STEM before they started their third year. This is not a surprise because universities and colleges often require students to declare before the end of the second year and joining STEM after the sophomore year would be much more difficult due to the large number of required prerequisite courses.

Prior Majors or Course of Study Before Joining STEM

We identified two distinct types of STEM joiners based on the participants’ responses to our interview question of their previous and current majors. The first group is students who left their original non-STEM major or intended non-STEM major and switched into STEM. We will refer to this group as STEM Switchers. Seventeen out of the twenty-two participants belong to this group. The second group is students who added a second STEM major while still keeping their original non-STEM major. We will refer to them as STEM Adders. Five of the participants belong to this group.

Motivation for STEM Joining: Why Did They Join?

Our first phase of inductive coding analysis revealed that the three most common factors that affected students’ decision to join STEM were STEM course preparation, experiencing supportive STEM environments, and individual mentoring from professors or graduate teaching assistants in STEM. We first describe each factor, using supporting evidence from our interview

transcripts. We then present the results of integrating these factors into the students' pathways of joining (or returning to) STEM based on our second analysis approach mentioned above and further interpret them

STEM course preparation

STEM course preparation refers to STEM classes taken before college or during college as a non-STEM major. All the respondents had taken several STEM classes before they joined STEM. This result is consistent with previous large survey analysis that STEM course preparation is positively correlated with STEM joining (Miller, 2018). Although all the respondents were not enrolled in a STEM major at the beginning of their college careers, they started taking STEM courses early in college, often before they joined STEM. These courses often were taken to fulfill college or university distribution requirements. Students' experiences in these courses often turned out to be critically important in the decision to join STEM. Respondents often reported enjoying the STEM courses and earning good grades (often to their surprise). The initial success prompted further interest in STEM and the taking of additional STEM courses. Thus, many students continued to take STEM courses even if those were not required for their original majors. Taking STEM courses early on in college could not only help potential STEM joiners develop interest in STEM subjects but also help them satisfy major requirements in STEM disciplines so that they can graduate on time even if they switch majors. This is especially beneficial and important because STEM majors often require many credits for a degree. Thus, early STEM course experiences could potentially increase the chance of becoming STEM joiners.

Next, we looked further into students' STEM course experiences, to find out what was special about these experiences that motivated students to join STEM. Two important aspects became evident: (a) supportive STEM course environments, and (b) individual mentoring from a faculty member or more advanced student.

Experiencing supportive STEM environments

Students often mentioned the importance of positive and supportive STEM course environments as one of their motivators to join STEM. For example, some respondents noted that in an introductory level, very large computer science course, a professor tried very hard to remember students' names and allowed students to call her on a first-name basis. Students reported that this level of familiarity was rare in STEM classes as professors in most STEM classes tend to be more distant from students. The professor's supportive approach made students who were new to STEM feel more comfortable to try out STEM courses. It also increased the likelihood that students would continue to take STEM courses, and therefore increased the possibility that students would later join STEM. The faculty member also stressed that the course was appropriate for students of all levels of ability and prior experience. Students reported that this

professor occasionally said in class, “close your eyes... raise your hand if you think we’re going too fast... raise your hand if you think we’re going too slow... raise your hand if you think we’re going just right.” Then, the professor would adjust the pace of instruction accordingly. The students often reported doing well in this and similar STEM courses, which possibly helped to negate the (often false) belief that they were not sufficiently talented or prepared to do well in STEM.

Individual mentoring from STEM professors, TAs, or peers

Many students also pointed out that there were specific faculty members or peers who provided substantial support in the form of mentoring in their STEM joining. By mentoring, we mean the naturally occurring, supportive relationships that students have with older and more experienced individuals. Mentoring often occurs outside of class, such as during office hours, at a club meeting, etc.

One respondent talked about having several conversations with the same professor:

He (the professor) called me... he was concerned I didn’t know what I was doing, so we met and then... he was worried that it was too much for me... he was surprised and pleased with how much work I was able to get done. So, junior year, actually by later sophomore year, I went through a phase of whether I should do a biology or chemistry major, and he asked me to do a chemistry major (a male junior English to Chemistry switcher).

As the students pointed out, having several conversations outside the classroom is not very common in STEM fields, but this professor volunteered his time to talk to students and created a welcoming and friendly environment. The professor did not blindly or selfishly push the student towards chemistry; instead, he showed concern for the students and paid close attention to their progress and development. The professor asked the student to switch to a chemistry major only when the student was ready, and his words directly affected this student’s decision.

TAs and other graduate students also often played key roles in helping to assuage students’ concerns and lack of confidence. Participants benefited substantially from graduate students sharing their own narratives about becoming STEM majors. Consider the following quote from a student who switched from sociology to chemistry:

many graduate students offering their perspective... talking with me about what to do in life and also... I realized that some of them actually did have quite a bit of interest in the social sciences... and were able to talk about some of the issues and politics in society pretty well, and I was surprised by that. And I realized that... you are able to still maintain a strong background in the social

sciences with the science major... so that's what I realized (a male senior Sociology to Chemistry switcher).

The student was afraid that a person with social science background would not succeed in STEM. TAs from the summer course helped him to understand that is not true, and this gave him the courage and confidence to study chemistry.

Many participants mentioned mentoring experiences either with faculty members or with TAs/graduate students, pointing out that these experiences were often critically important in their decision to join STEM. The interaction often went beyond attending classes and became more personal and meaningful. These themes emerged as students constructed their STEM identities and pathways into STEM by telling us their narratives.

Career considerations

Many students attributed their decision to join STEM to career concerns in the other major; the students were concerned that they might not be able to find a job in their original major, and that either joining or adding the STEM major would help in this regard. This factor was brought up mostly by double-major students who added a second STEM major to their original non-STEM majors. Computer Science was the most common second major. Computer Science is a flexible major that can be added to almost any other major (Margolis & Fisher, 2003). Students cited many different reasons for better career outcomes with their added computer science major. For example, one student thought her two majors – communication studies and computer science – supported her goal of finding a career in human-computer interaction. She realized that adding a computer science major would give her more opportunities and reduce the risks associated with finding a job in the film industry. She observed,

I bookmark articles all the time on my computer, and I just screenshot everything about, like, how there's someone right now going to uhh... the Silicon Valley to try to get people to go into defenses instead of going into, you know, these other industries within computer science. And I'm just looking at these, thinking I would love to do this (a female junior Communication Studies and Computer Science STEM adder).

Likewise, another student chose to add a computer science major because it is more related to her original journalism major. She said, “there is more overlap” and she wanted to use computers to tell stories.

Therefore, these students joined STEM not only because they had interest in it, but also because they considered STEM to be something useful for their career path, even if STEM was not their only major. Earning a STEM degree would equip them with knowledge and skills that they need for their desired career.

Synthesis of Themes and Categories

Having identified the key influencers of students' STEM joining decision, we then contextualized these key factors into a developmental trajectory that describes routes to becoming a STEM joiner. Our coding and analysis revealed that students' trajectory of becoming STEM joiners often consisted of three core stages or processes (see Figure 2): a) initial interest in STEM, usually in high school or even before b) leaving STEM fields before or when coming to college; and c) joining (or returning to) STEM. This trajectory describes most but not all respondents' journeys, and it is especially relevant for the STEM Switchers. Figure 2 provides a summary of both students' narratives and the elements that emerged in the inductive coding.

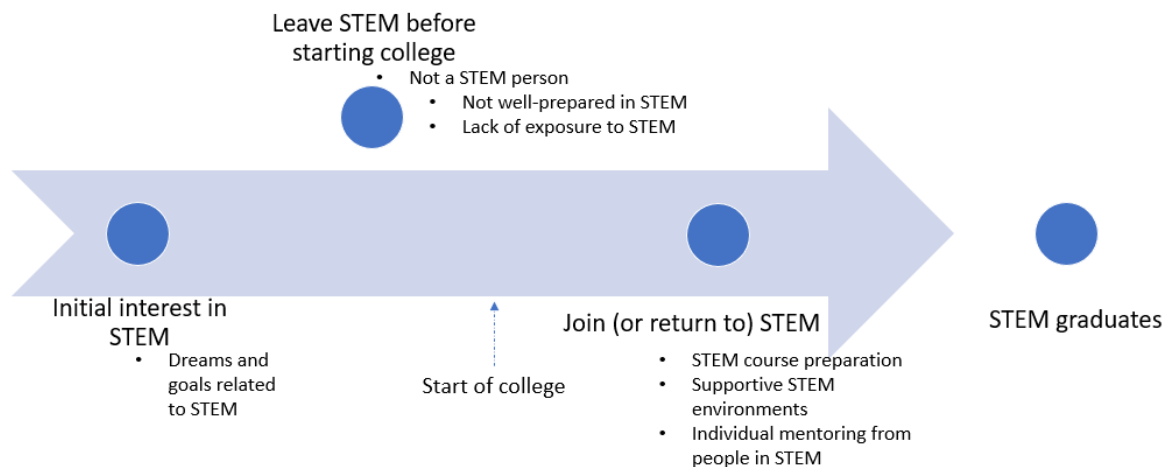


Figure 2. A possible pathway of STEM joiners from pre-college to college.

Initial interest in STEM

As Figure 2 shows, the trajectory usually began with students' dreams and goals related to STEM before they came to college. Many students reported that they had been interested in STEM topics in high school or earlier and had seriously considered declaring STEM majors in college. They had also completed the necessary high school courses to allow them to begin a STEM major in college, and many reported taking several Advanced Placement courses in Chemistry, Physics, Biology, or other STEM topics.

Deciding initial not to pursue STEM

Once the students began taking college courses, their initial plans or desires to major in STEM began to fade. Many of the respondents expressed anxiety about whether they would succeed in a STEM major, with many attributing the problem to a lack of adequate high school

preparation. This (often false) belief may have arisen students comparing themselves to other students in the prestigious universities or colleges. Thus, they concluded that they were not a “STEM person” and decided not to pursue a non-STEM major. (Note that this could also happen in college).

For example, one participant who switched to chemistry from sociology said, *“my dream was to become a doctor, but then my high school was not really strong in the sciences... it was actually pretty strong in the social studies.”* He dreamed of have a STEM-related career while he was young, but he thought his high school didn’t prepare him well enough for a STEM major. That hindered him from entering a STEM major when he came to college.

Another student who later switched into math expressed a similar idea. *“So I’ve always wanted to do something with science and math. I just, there were so many things in my way... So yeah I’ve always had that in the back on my mind. I just never had the courage, you know, to do it. And I never thought I was good enough.”* The assumption that they lack the necessary confidence or preparations seems to be a key factor in leading students to leave the STEM pipeline.

Joining (or returning to) STEM

Nevertheless, the students still took STEM classes, perhaps simply because these classes were often required as curriculum distribution requirements. Thus, even though they thought they would no longer major in a STEM field, they still ended up taking some STEM courses. These courses proved to be very important in their decision to change (or add to) their current major and return to their original interest in STEM. The courses supported the return to STEM in at least two ways. First, they helped the students to see that they could succeed, despite their beliefs that they were underprepared or underqualified for STEM majors. Second, in the context of taking these STEM courses, the students often experienced the supportive STEM environment with help from mentors, either professors or graduate students. The mentoring experiences helped to reinforce the nascent belief that the student could succeed in a STEM major, and also provided a forum for asking questions, addressing doubts and concerns, and learning about other students who had followed a similar trajectory. Consequently, they decided to “return” to STEM and pursue their original interest.

STEM joining is thus often part of a larger narrative in which the act of joining STEM is actually viewed as a return to one’s true interest. Students often reported being happy about their decision of coming back to STEM; their interview responses often conveyed a sense of found purpose or meaning. The students saw joining STEM as much more than being forced to study popular majors that they did not like; it was actually a decision that led them back to something they had enjoyed (usually in high school) and had truly wanted to pursue. The overall trajectory traced back to students’ experiences before college and sketched out their journey in college.

Discussion

The STEM shortage is one of the most severe challenges in American's workforce. STEM joining is a potentially critical but often overlooked component of the overall supply of STEM majors; STEM joiners can help to replenish some of the "leaks" in the STEM pipeline. Efforts to produce more STEM workers should go beyond just preventing students from leaving STEM and should be expanded to include motivating students to join STEM. This paper has considered the motivations and developmental trajectories that lead college students to join STEM.

The results reveal that students' decisions to join STEM involves far more than the decision to switch or add a STEM major. The students did not suddenly have an epiphany that led them to switch to or otherwise join the major. Instead, the decision to join STEM must be viewed in a dynamic, developmental context in which various experiences have changed and reshaped students' choices and beliefs.

Finding that students may join STEM from another major is not new, but highlighting the narratives that students construct around joining STEM is a novel contribution of this paper. Identifying these narratives helps to expand conceptions of the causes and remedies for the STEM shortage. "Leaking" from the pipeline is indeed a serious concern, and most of the students in our sample saw themselves as "leakers" from the pipeline; many had intended to major in STEM and had taken the necessary high school courses, but they chose another non-STEM major in college. However, our results also illustrate a fundamental limitation of the Leaky Pipeline metaphor: the "leaking" was not necessarily the end of the story---some students did return to STEM. The leaky pipeline metaphor has perhaps led us to ignore the more complex but much more interesting developmental pathways that are associated with the decisions to enter, leave, persist, or re-enter STEM fields. Such rich details were only available to us through the in-depth qualitative interviews and the grounded approach to our analysis.

Moreover, our findings revealed that STEM joiners often had three common characteristics: early STEM course preparation, supportive STEM environments, and receiving individual mentoring. These characteristics have received some coverage in prior research on STEM pathways (e.g., AAUW, 2010; Ong et al., 2011; Stout et. al, 2011; Wang & Degol, 2013), but our qualitative approach allowed us to have more of a contextual narrative for these characteristics.

It is well documented that early STEM course-taking and the associated grades can often predict students' original declaration of STEM majors or retention and persistence in STEM (e.g., Bottia, et al., 2015; Riegle-Crumb, et al., 2012; Tyson, et al., 2007; Wang, 2013). However, these studies only consider major selection in STEM as a unidirectional process. On this view, STEM students either persist or they leave the majors. Our research suggests early STEM course-taking

also influences whether students who leave STEM ultimately return, or whether non-STEM majors add a second, STEM major. Thus, the decision to add, leave, or return to a STEM major is part of a larger and fluid developmental process.

Similarly, our work may support taking a different perspective on the influences of campus culture, especially for women and underrepresented minorities who often experience stereotype threats in STEM (e.g., Espinosa, 2009; Johnson, 2012; Ramsey et al., 2013; Szelényi et al., 2013). Almost always, these studies focus on whether the campus culture promotes STEM persistence; these studies usually do not consider majoring in STEM as a dynamic and evolving developmental process. Our research, on the other hand, expands the findings of the previous research and provides evidence for the possibility of re-entering STEM. It is important to examine whether increasing STEM joining could help to increase the number of women and minorities who major in STEM.

Previous research has also shed light on why factors such as individual mentoring from professors or peer advisors strongly influenced students' development and major selections. Individual mentoring and providing role models help to confront the stereotype that pursuing a STEM major is difficult and prone to failure. Prior research has shown that such mentoring can contribute substantially to persistence, and here we showed that mentoring could play a critical role in STEM joining. Once a student has "leaked" from STEM, a supportive mentor may be the key factor in helping the student to see the possibility of returning to STEM. The success of the role model becomes a positive representation of the original underrepresented population, and students may then seek to emulate this positive role model (Eschenbach, 2015). At the same time, peer advisors play an important role because the experiences they shared demonstrate the difficulties are shared.

Limitations

There are some limitations of the study we need to recognize. Firstly, our sample size is not large, but our focus was on a qualitative, detailed analysis of individual participants. Our results suggest potential approaches and questions for future research. For example, the "returning" pathways might be further investigated in future quantitative research. Secondly, our results do not reveal much about how experiences and narratives may differ for different genders or races. We did not focus on gender or racial differences in our study, as our goal was to explore the under looked group of STEM joiners and illuminate some of their experiences and trajectories. In the future, researchers could ask specifically whether and how people with different gender and racial backgrounds differ in their experience of joining of STEM. Thirdly, our research only examined STEM joiners and therefore we could not identify whether these experiences were unique to STEM joiners or could also be found on STEM leavers. Future research can compare joiners and other groups (e.g., STEM leaver or STEM stayers). Finally, more

information could be gained if we follow students and interview them multiple times, including after they graduated.

Implications

There is more to the STEM supply problem than leaks; a lack of replenishment through STEM joining is also a serious problem. Therefore, the solution to the STEM shortage cannot be only to fix the leaks. Instead, to fully understand, and perhaps to redress the STEM shortage, we need to consider what happens after the “leak”. A relatively small but potentially important group of students do return to STEM after they have “leaked”. Facilitating STEM joining or returning could substantially increase the number of successful STEM graduates in the U.S. Encouraging students to join STEM after starting a non-STEM major might be a very effective and efficient way to address, in part, the STEM shortage. We acknowledge that our results were based on a qualitative research with a sample of 22 participants, and more research is definitely needed, but we also believe that these results could already enable us to make some suggestions on how to potentially encourage STEM joining.

Addressing false beliefs about preparation for STEM

In this regard, the results do shed light on some possible ways to increase the number of STEM joiners and to make those considering STEM majors more comfortable and confident in that decision. For example, one important remedy would be to address students’ beliefs that they were not adequately talented or prepared to study STEM in college. We have labeled this a false belief because it is empirically not true; almost all of participants had more than adequate preparation to pursue a STEM major, as defined by the relevant departments. For example, almost all of our respondents had taken four years of math and science in high school. Moreover, many had taken and done well in several STEM Advanced Placement classes. Nevertheless, they consistently reported feeling underprepared to be a college STEM major.

Students’ beliefs about inadequate preparation or qualifications for majoring in STEM may be an example of pluralistic ignorance, in which many people in a group hold the same false belief but are not aware of others’ beliefs (e.g., Miller & McFarland, 1991). If so, some of the same techniques that have been shown to be effective for redressing pluralistic ignorance may work in this situation as well. For example, posters, brochures, or social media campaigns aimed at increasing or retaining STEM majors might point out that many people falsely believe they are not qualified to major in STEM, but that this belief is incorrect. The technique of correcting pluralistic ignorance to address a social problem has worked in other contexts, such as reducing alcohol use among college students (Schroeder & Prentice, 2006). Telling students that many of their peers did not drink helped to reduce the pluralistic assumption that most college students drink heavily, which in turn made sobriety feel more normal. Likewise, explicitly telling students

that many feel unprepared to study STEM, but that they are adequately prepared, might help to address this consistently held false belief.

Mentoring

Faculty need to be made aware of the possibility of STEM joining, and the important role that they may play in instigating the move back to STEM. University mentors can now be explicitly aware of the “returning to STEM” trajectory, and they may help students realize their potential and fulfill their goals. First-year college advisors could be made aware that students’ claims of “inadequate preparation” might be an indirect indication of a loss of confidence. This would allow the advisors to help initiate the mentoring that proved so critical in the decision to join STEM.

Curriculum considerations

Our results suggest that all the STEM joiners started taking STEM courses even before they officially “joined” STEM, and many noted that their success and enjoyment of these courses contributed to their decision to return to their original, intended focus on STEM. This finding suggests that both the timing and quality of early STEM courses may contribute substantially to increasing the number of STEM graduates—both by preventing leaks and by promoting STEM joining. Students who are taking STEM courses and are not STEM majors could be a potential source of STEM joiners. To increase the number of potential STEM joiners, STEM departments at universities could reconsider their curriculum design and offer more STEM courses for non-major students and perhaps require these courses to be taken early in students’ careers. By doing so, students majoring in non-STEM fields would have the opportunity to experience STEM courses. Our results suggest, in fact, that these students may enjoy and do well in these early STEM courses. This experience could change their perception of STEM and revise potentially destructive false beliefs about lack of competency or preparation.

In this regard, we note that there is substantial variability across colleges and universities as to when students are required to take STEM courses. Some colleges and universities may require some STEM courses as part of the core curriculum, which is typically in the first year of college. This early exposure to STEM might increase the chances of the STEM-joining trajectory beginning. Moreover, universities can also consider establishing more joint degree programs between STEM and non-STEM majors, to increase the number of STEM adders, and therefore ultimately increase the number of STEM joiners. (Blinded) University’s dual degree programs, in communication and engineering or in music and engineering, are good examples of this practice.

Conclusion

This paper presents and illustrates a developmental pathway for STEM joiners: when viewed in a broader, developmental context, we see that joining STEM and leaving STEM are often related. The decision to join STEM in college is often viewed by the students as part of a larger trajectory that includes their initial interests (e.g., in middle and high school) in STEM, followed by a decision not to pursue these initial interests in college. However, because of positive experiences such as doing well in STEM classes and encountering supportive mentors, the students revised the decision to leave and thus became what we are calling STEM joiners. They are not just joining; they see their journey as one of return to their earlier, “true” interest in STEM. Our results therefore highlight the value of examining the processes of entering or leaving a major from a developmental perspective that takes into account of the dynamics and fluidity in the adult development process (e.g., Arnett, 2009; Arnett, 2016; Murphy et al., 2010). The leaky pipeline implies a unidirectional flow—out of STEM. But considering the nascent and sometimes fragile nature of young adults’ developmental trajectories, we were able to bring to light a non-linear pathway that emphasizes both leaving and returning. Thus, a developmental perspective can help to take us beyond reliance on the influential but often misleading metaphor and provide insights on a broader picture of students’ development.

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Appendix A

Interview Protocol

Categories	Example questions
<i>Demographic information</i>	<ul style="list-style-type: none"> • What is your current major and what was your previous major? • Which year are you in school now? • When (which quarter) did you join STEM?
<i>Pre-college</i>	<ul style="list-style-type: none"> • Is STEM always something you wanted to do since you were young? • What did you want to do when you were a kid? • How were your science classes in high school? • Were you a science person in high school?
<i>Decision process</i>	<ul style="list-style-type: none"> • Why did you join STEM? • Did you take any STEM courses before picking up a STEM major? • Is there any specific person who played an important role in your decision process? • Can you walk me through your decision process of joining STEM?
<i>STEM vs. non-STEM</i>	<ul style="list-style-type: none"> • Do you think STEM majors are different from non-STEM? Why?

Note that the interviews were all semi-structured, which means we asked follow-up questions based on participants' responses to the questions on the interview protocol.

Appendix B

Coding Scheme

Categories	Definition	Example
Dream/goal related to STEM	Students' pre-college experience regarding their dream and goal in STEM.	<i>"So I've always wanted to do something with science and math. I just, there were so many things in my way... So yeah I've always had that in the back on my mind."</i>
Lack of exposure to STEM in high school	Students' STEM experience in high school.	<i>"my high school was not really strong in the sciences... it was actually pretty strong in the social studies"</i>
Not a STEM person in high school/not well prepared	Students' self-perception in regard to STEM in high school.	<i>"I never thought I was good enough."</i>
STEM course experience	Students' college experience of taking STEM classes.	<i>"I took EECS 111 in the fall sophomore year and just had a really good time with it. It felt very comfortable to join the major after that."</i>
Supportive STEM environment	Feeling welcomed and being supported in STEM classes.	<i>"close your eyes... raise your hand if you think we're going too fast... raise your hand if you think we're going too slow... raise your hand if you think we're going just right."</i>
Mentoring from professors	Receiving advice and guidance from professors outside of class.	<i>"His passion about math was just kind of infectious...He was part of the reason that I even declared my math major...and I actually ended up emailing him a little bit after I decided not to do MMSS, just kind of asking him what kind of career paths, you know, people with a math degree."</i>
Mentoring from TA/graduate students	Receiving advice and guidance from TAs or students	<i>"many graduate students offering their perspective... talking with me about what to do in life and also... I realized that some of</i>

	graduate students outside of class.	<i>them actually did have quite a bit of interest in the social sciences... and were able to talk about some of the issues and politics in society pretty well, and I was surprised by that. And I realized that... you are able to still maintain a strong background in the social sciences with the science major... so that's what I realized."</i>
Peer advice	Receiving advice from peer students.	<i>"I didn't know about this major until one of my friends, who is a year older than me, told me about the manufacturing design engineering major."</i>
Career consideration	Considering future career planning.	<i>"I bookmark articles all the time on my computer, and I just screenshot everything about, like, how there's someone right now going to uhh... the Silicon Valley to try to get people to go into defenses instead of going into, you know, these other industries within computer science. And I'm just looking at these, thinking I would love to do this."</i>
Family	Being influenced by family background or getting advice from family members.	<i>"My parents both came from very scientific backgrounds; they both went to medical school. I don't want to say influenced as in they forced me cause that sounds bad, but like... cause, like, if you're just surrounded by it and you're naturally curious about it, then you automatically have an interest in it... Yeah, they influenced me, but they didn't, like, push me or force me to do it."</i>