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Exploring engineering students' reflections of their childhood experiences: The intersection of structure and curiosity

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Abstract

Explorations into students' narratives of their pre-college making pathways inform our understanding of the nature of early making experiences prior to entry into undergraduate engineering programs. Through our student interviews, four pathways were identified based on the nature of how the activities were structured and the outcomes of the activities. Each of the two constructs identified were further differentiated into two poles identified as structured activities versus unstructured activities and specific curiosity versus diversive curiosity. Self-directed, unstructured activities are ones where individuals identified that their own independent work was performed with a great deal of autonomy in both how and what was explored. With structured activities, the individuals did not self-impose or seek out the activity, but rather, the activities were laid out by a mentor or expert. Specific curiosity is where a clear path in the form of a certain activity is started to gain a particular knowledge or skill. With curiosity of the unknown, however, an activity was undertaken for the pure exploration or interest with no identified outcome or specific knowledge gained. Using these definitions, the four pathways that emerged were structured-specific, unstructured-diversive, and unstructured-specific and structured-diversive. From the interviews collected and analyzed in this research from self-identified makers, three out of the four pathways are identified: structured-specific, unstructured-diversive, and unstructured-specific. Structured-diversive is absent in our dataset. We propose that the absence of structured-unknown activities is a result of the population interviewed rather than its absence among pre-college individuals.

1. Introduction

Pause and Reflect: *What led you to choose your academic major in college? Was it a positive experience? The recommendation of a person? A favorite activity, event, or club? Or perhaps the experience wasn't positive or memorable at all, but instead, something to overcome?*

The experiences of children and adolescents are often foundational to their decisions to declare a particular major in college [1]. Influential experiences become memorable experiences for their ability to pique the children's interest and maintain that interest over time; it is these memorable experiences in which we are most interested. Over the past several decades, there has been an influx of curricular, co-curricular, and community programs designed to develop children's interest in Science, Technology, Engineering, and Mathematics (or STEM) related activities. Many such programs are designed to increase participation by individuals often considered underrepresented in STEM (e.g., girls and students of color), and thus, pipelines are created to and through college for STEM related disciplines. This has particularly been the case for engineering with making-related programs that allow pre-college age students to apply engineering concepts through design and making in makerspaces. As a result, many engineering students arrive at college with a wide range of pre-college experiences; this preparation has led us to ask: *Which experiences influence pre-college age students' path into STEM?*

Toward answering this question, this paper explores the lived experiences of a group of students enrolled in a non-disciplinary engineering program at a mid-Atlantic, primarily undergraduate, comprehensive, public university. For these students, we examine their described pathways into engineering by identifying and defining the types of influential experiences on the constructs of highly structured activities to completely unstructured activities and those driven by certain forms of curiosity. Their pathways provide insight into the overlapping experiences of learning in *formal* educational settings as well *informal* settings such as the home. Defining these activities allows for a clearer understanding of what constitutes influential from the perspective of students majoring in engineering and can help educators tailor future outreach programs to target diverse groups of students more effectively and more broadly develop STEM interest.

2. Background

Within the U.S. over at least the past decade, there have been repeated calls for increased STEM education in the K-12 curriculum as a pathway for supporting development of creative and innovative technology solutions [2]. Research conducted by Sheridan seems to support these calls, finding that critical thinking and analysis skills previously thought to be unreachable until higher education levels can be reached by kindergarteners [3]. Waltston found that harnessing the interest of children as young as kindergarten allows for greater independent problem-solving skills [4]. For those in STEM fields, these findings may not be surprising. Interviews conducted with people working in the STEM fields reflect the importance of K-12 experiences and how familial and educational aspects influenced their career path [5-7].

In addition to early childhood programming, high school math achievement appears to be a critical factor in intent for a student to major in a STEM discipline. For example, exposure to different math and science courses prior to enrolling into a post-secondary institution is demonstrated as important for a students' math self-efficacy [8]. Unfortunately, there is leakage in this mathematics pipeline, and the number of students interested in STEM topics is not proportional to those enrolled [9]. In Virginia, one approach to address this issue is the Governor's STEM school. Students who attend the Governor's STEM school are more likely to major in a STEM subject if enrolled in a post-secondary institution, highlighting the importance of high school in persistence through STEM [10].

Once students enter college, statistical hurdles to success persist. STEM majors transfer to other majors at higher levels than non-STEM majors with over half of mathematics majors switching [11]. Two key character strengths identified in *The Process of Choosing Scienc*e as important for persisting through positive and negative experiences during college and remaining in a STEM field are: 1) expectations for success and 2) individual value on success [12]. Previous pre-college and college success in math and science, support from mentors, and support from peers are also noted as critical [12]. Lent et al. found that students' persistence is related to self-efficacy, outcome expectations, interests, and goals [13]. Fortunately, research on character strengths has demonstrated that they do change over time and can be positively influenced by factors such as culture, environment, and affirmation [14]. The dynamic nature of character strengths points to the potential importance of early childhood experience for bolstering both interest and persistence in STEM majors in college. This opens the door to examining development based on the makeup of the personal experiences of pre-college age students.

Two constructs were identified in the pathways of students whom we studied in this research: curiosity and structure. Curiosity in this context refers to the main source of motivation for engagement in each activity as an exploratory behavior; this working definition is derived from Harvey [15]. Structure in this context refers to physical organization of an activity and the degree of which additional people are involved; this working definition is derived from Meeks and Mauldin [16].

2.1 Curiosity

For curiosity, it is difficult to find both a common and encapsulating definition as well as a means for measurement [17]. Perhaps one of the earliest definitions comes from William James in 1899 that curiosity is "impulse towards better cognition" [18]. The lack of a clear definition may be attributed to the use of a variety of measurements for curiosity and expression [19]. Three models for curiosity seem to be most prevalent:

- **Trait Curiosity:** Trait models of curiosity indicate that curiosity levels expressed by a person are constant regardless of engagement. The Five-dimensional Curiosity Scale developed by Kashdan is one such model and includes the following constructs: Joyous Exploration, Deprivation Sensitivity, Stress Tolerance, Thrill Seeking, and Social Curiosity [20]. Scales, such as Five-dimensional Curiosity, provide value by mapping one's 'curiosity' to personality traits to predict possible reactions. Practicality, though, is questioned as it is not clear how individuals may capitalize on identified curiosity [21].
- **State Curiosity:** State curiosity is the curiosity as expressed by a person at any one given time. The most comprehensive work on state curiosity was developed by Berlyne. Berlyne separates curiosity into perceptual and epistemic where perceptual is the curiosity produced through novel stimuli, and epistemic is that produced through desire of knowledge [22]. Applications to education were introduced by Robinson who examined children's responses to observe how posing questions influences curiosity [23].
- **Exploration:** Curiosity acts as the driving force towards the exploration of various captivating topics where concepts relate directly to the two dimensions of state curiosity, perceptual and epistemic, but also combine the want to do something with an actual action [24-25]. Exploration is a precursor instead of an end indicating practical insights into ways to induce and encourage this type of coveted behavior in work settings [26].

2.2 Structure

For structure, there are many existing differentiations between the role of the learner, their interactions with others, and the physical environment during an activity. Sheridan et al. uses learning arrangements to describe these compositions, recognizing solo projects, collaborative group projects, equipment training, as labels to various making activities [27]. The idea that multiple learning arrangements exists and thus the ability to specifically structure an activity to induce specific characteristics of the experience has been awarded with the potential to increase the equity of learning to students [28]. Two overarching categories of activities then exist:

- **Unstructured:** Often a major category within unstructured learning is play-based learning, which due to a lack of a concrete definition, has been described using the instinctual understanding of what "playing" as a child means [29]. Despite the lack of a clear definition, many characteristics of play-based learning have been identified including activities that are self-initiated, spontaneous, voluntary, enjoyable, and ‘purposeless’ [30]. The notion of play as aimless, though, does not account for activities satisfying one’s personal characteristics, desires, or interests. Sheridan et al. termed these activities ‘solo projects’ noting their prominence in makerspaces [27].

- **Structured:** Within structured activities are organized activities, which refer to those activities having some level of coordination, either supervised or focused, and often, these activities are focused on skill improvement [31]. Organized activities can occur within school-curricula, during leisure time with activities like hanging out with friends, in school-based clubs, and even chores [32]. When investigating activities through the perspective of ‘providing a learning experience,’ the findings of Hughes are supported: Support can be critical to persistence in STEM [12].

3. Research Questions

The increasing need to diversify STEM fields and stop the leakage of students from the STEM pipeline calls for us to look not only at discrete decisions along the pipeline, such as major declaration, but rather a continuum of activities and experiences that move students through and toward STEM majors. This becomes a reason to understand the key activities and the impact of these factors which lead to young students’ decisions. Toward understanding these activities and their role on young students’ decision making, we pose two research questions:

RQ1: *What are the types of impactful pre-college activities engineering students participated in encouraging them to major in STEM?*

  a. *What are the different types of structures present in an engineering students’ timeline to major declaration?*
  b. *What is the exploratory curiosity of the activities present in an engineering students’ timeline to major declaration?*

RQ2: *What are the different pathways engineering students took before declaring their major?*

4. Methodology

The data used in this research were collected as a part of a larger study on learning through making in a university engineering program. The data were collected based on a series of phenomenologically based interviews of students who self-identified as makers and enrolled in a general engineering program within a mid-Atlantic University. Nine students were interviewed by a single graduate student enrolled in a communication studies program at the same university. Interviews resulted in a total of 756 pages of single-spaced transcripts. The methodological process as applied for data collection is detailed in *Studies in Engineering Education* [33].

4.1 Participants

Using snowball sampling, participants in the study were recruited among engineering students at a large, public university in the mid-Atlantic. Participants all self-identified as makers. Of the nine students interviewed, five students identified as men, and four students identified as women. Four students were sophomores at the time of the interview or had just completed their sophomore year and not yet begun their junior year. One was a junior, and the remaining four were seniors. Three of the nine students self-identified as part of a racial or ethnic minority; the remainder were white.

4.2 Semi-structured Interviews

Each of these nine students participated in three 90-minute long phenomenologically based interviews [33, 34]. The goal of the phenomenologically based interviews was for the participants to reflect on their making experience, with each of the three interviews focusing on a specific aspect of their lived experiences toward becoming an engineering student and maker. The first interview focused on the participant sharing their life story related to making. During the second interview, the conversation revolved around an artifact brought in by the participant. During the third interview the participants were asked to create and reflect on a timeline of their making experiences. Student participants were interviewed in-person in a private office on the university campus by a graduate student studying at the same university and working toward an MA in Communication and Advocacy.

4.3 Data Analysis

Data analysis followed an abductive process outlined by Tracy [35]. The researcher began with a data immersion phase spending three months reviewing all nine participants' interviews. Primary cycle coding began after reading each interview fully once. Visual maps of the data, such as the one shown in Figure 1, were then constructed to portray a timeline for each of the participants which acted as a secondary source of data. The third interview in the set for each participant was used as the basis for the recreation of the timeline and subsequent interviews were then used to add additional information.

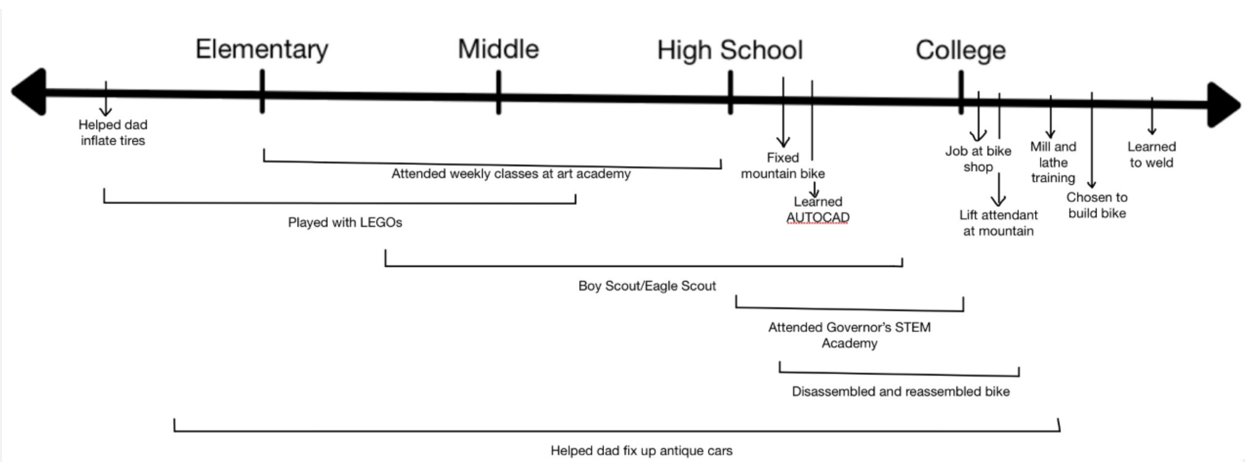

Figure 1: Example of Recreated Timeline Based on Student-Maker Interview

Timelines were developed based on participant-described activities. Activities were placed based on time periods including elementary school, middle school, high school, and college, and singular activities versus repetitive or longer activities were represented as such on the timelines. During the creation of the timelines, analytical memos noting initial interpretations were developed, serving to provide context to activities on the timeline and organize emergent themes.

Exploration of the four major emergent themes was done by use of overlaid color coding by hand on each of the nine timelines. The first round of color coding used the derived, individual timelines as a basis for comparison of different types of activities or events such as jobs, family-oriented activities, and disruptive or negative experiences participants noted as important to their journey into making. Each activity was also categorized based on what the original researchers

Table 1: Types of Structured and Unstructured Activities

Type	Explanation	Example
Structured	Initiated and/or facilitated by someone other than the student.	
1. Curriculum-Based	Activities that occur within an educational setting, and learning is a result of formalized classes or projects.	"I took an engineering class my senior year with Big University, and I liked it so I was just like 'I'll just go to college for it, I guess'."
2. Extracurriculars	Activities that are formalized in some manner but not mandatory and offer ability to exercise choice in involvement. Examples include clubs and volunteering	"There was a club new to campus which was the 3D printing club… So I really got started with that"
3. Family Socialization	Family member of student is acting as the mentor; work is often related to jobs, responsibilities or hobbies of family members.	"And when I was a kid, I was always um, forced into working with [my dad] on that kind of stuff uh, home projects and stuff"
4. Work-Based	Learning as a result of experience from a paid job.	"And then I ended up getting a job at a bike shop, too."
Unstructured	Initiated and facilitated by the student themself.	
5. Play-Based Learning	Activities where no end goal is explicitly identified.	"My parents bring this up often, I had a very active imagination…we always had a lot of boxes when I was a kid and I would make fortresses."
6. Solo Projects	Activities where a project is started with the intent to achieve a specified end result.	"And the director said that we could use plastic mouthpieces if they were all the same color and none of us wanted to buy another mouthpiece… So I made a CAD model…and 3D printed them in one of the makerspaces for the trombone section."

termed "curiosity of the known " or "curiosity of the unknown. The activity types were grouped into structured and unstructured; themes were given definitions and meanings before going through a second round of color coding to validate the emergent codes. The final round of color coding for the timelines grouped all the structured activities into one category; unstructured activities were grouped into another category. Then, the two types of curiosity were marked creating four distinct pathways. Defining the pathways for each of the participants was completed by using the colored timelines to visually indicate the relative quantity of either structured or unstructured activities and diversive or specific exploration.

5. Results

Based on the nine timelines created from the participant interviews, themes based on the structure of the activities described were identified. Researchers first noted the difference between inherently structured activities and unstructured activities, indicating the level of autonomy the participants had in their involvement with each activity. Within these two broader categories, further differentiation was based on the type of activities.

5.1 Category Types and Exemplars

Listed as Table 1 are the six categories that define the structure of an activity. Curriculum-based activities, extracurriculars, family socialization, and work-based are the four categories within structured. Each of these four activity types are considered structured because of the influential involvement of another individual during the activity. We found these structured activities to be institutionally formalized with the exception of family socialization where the strong presence of a mentor exists for our dataset regardless. Unstructured activities include play-based learning and solo projects. Both of these share the participants strong autonomy to engage in the projects and the absence of an outside mentor acting as the primary means of accomplishing the tasks.

In addition to the structure of the activities, themes emerged in the type of curiosity expressed during the activity. The researchers originally termed the two types as: curiosity of the known (specific exploration) and curiosity of the unknown (diversive exploration). Although both types of curiosity represent an interest and engagement in the activity, they are distinctly different in the motivations of the participants for a given activity. The two types of curiosity are listed in Table 2 as are examples where the participant engaging in diversive curiosity is doing so out of a "fascination." Each specific example shows the participant choosing to take training with the wish to learn a certain skill set.

5.2 Thematic Pathways

Using the themes found within the timelines, specifically during participants' K-12 experiences, four pathways emerged:

- Structured-Diversive: Defined as activities where an outside mentor facilitated an activity in order to be immersed in an activity because it is new and interesting to them.
- Structured-Specific: Defined as activities where a particular outcome or piece of knowledge needs to be obtained through an activity that is facilitated by someone.
- Unstructured-Diversive: Defined by an activity where the person of interest is also the facilitator seeking stimuli from engaging in the activity.
- Unstructured-Specific: Defined as activities completed solo for the purpose to gain knowledge in a particular area or skill set.

Table 2: Types of Exploratory Curiosity

Type	Explanation	Example
Diversive Exploration	Curious nature invoked by want for new stimuli usually caused by feelings such as boredom.	"I like making things. I like making functional things and I had this fascination with duct tape because it was sticky and stuck places…I used to carry [duct tape] in my backpack and people paid me for wallets."
Specific Exploration	Curious nature invoked by a want to gain new information.	"I want to perfect – or keep learning in each. Maybe a bit more 3D printing training, laser cutting training."

Figure 2 illustrates these pathways as we understand them: four quadrants - in other words, activities exist on a continuum of structuredness and curiosity. For our nine timelines, two represented the unstructured-specific category, two represented the unstructured-diversive, and five represented the structured-specific pathway. The absence of structured-diversive activities within the data set is hypothesized to be a result of the population interviewed rather than its absence among pre-college individuals as the research group; when discussing examples for each pathway, we could imagine potential activities as structured-diversive even though they were not identified. Timelines that follow Figure 2 use the convention provided in Figure 2: Solid black lines to indicate structured, dashed lines to indicate unstructured, bold words to indicate diversive, and italicized/underlined words to indicate specific.

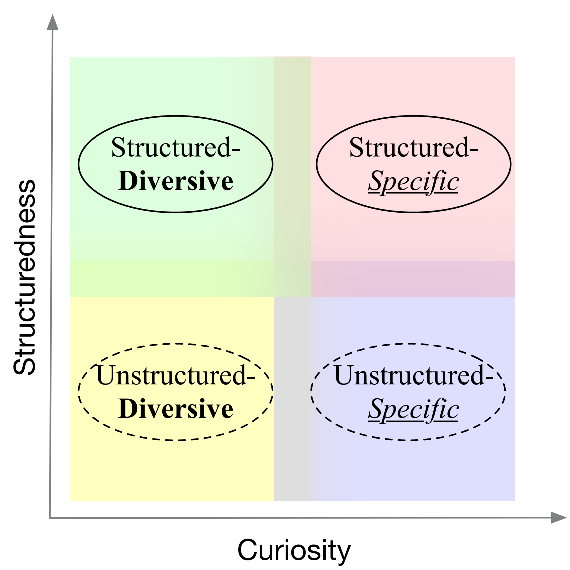

Figure 2: Matrix of Structuredness and Curiosity

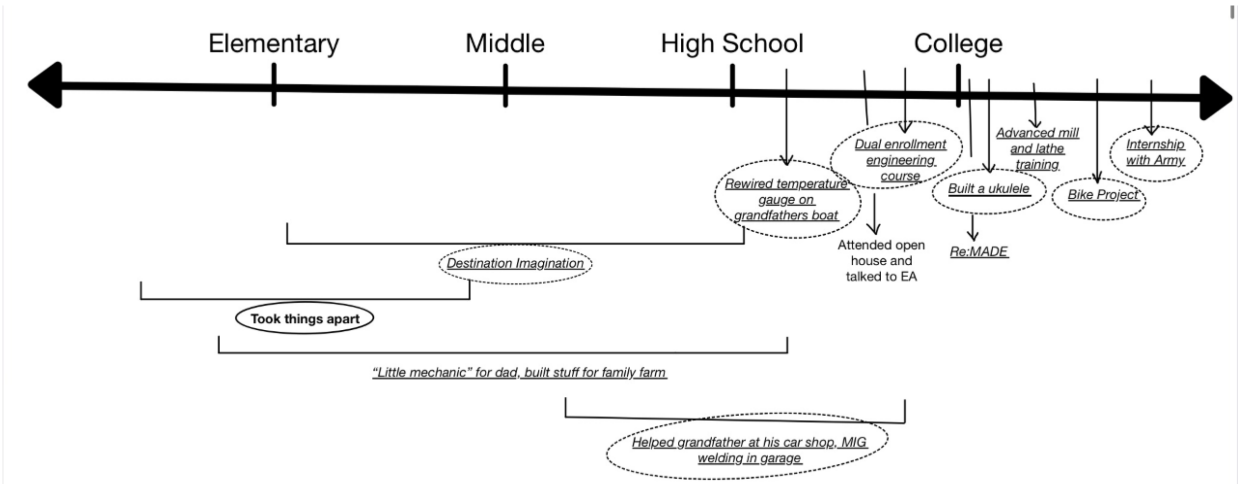

Figure 3: Example Timeline for Structured-Specific Pathway

5.3 Example Timelines for Identified Thematic Pathways

Figure 3 is an example of a timeline with the structured-specific pathway. This pathway is defined by an abundance of activities during K-12 that were not self-imposed as well as activities undertaken to gain specific information. The participant timeline provided as Figure 3 includes involvement in education activities such as Destination Imagination, activities where the participant helped her father and grandfather, as well as formalized classes revolving around learning a technical skill set, all of which fall under the structured category. The nature of these activities exemplifies specific exploration as many of her endeavors like fixing her grandfather's boat or choosing to take a dual enrollment engineering class were done with the intention to gain specific knowledge.

A timeline representing the unstructured-diversive pathway is provided as Figure 4. The unstructured-diversive pathway has characteristics that include activities which show a large degree of autonomy in the choice of topic and pursuit as well as ones where the choice to explore was not done to learn any specific pieces of knowledge. Figure 4 is of a participant who often would take it upon herself to use common materials around her in making and artistic endeavors like using cardboard to build a car or making duct tape wallets. In most of her activities within her K-12 experience, the participant merely began activities of her own cognition and out of pure enjoyment for hands-on experiences and making.

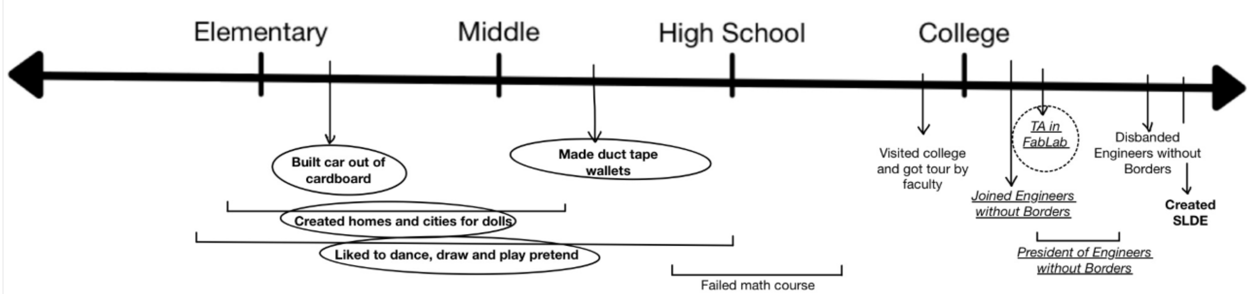

Figure 4: Example Timeline for Unstructured-Diversive Pathway

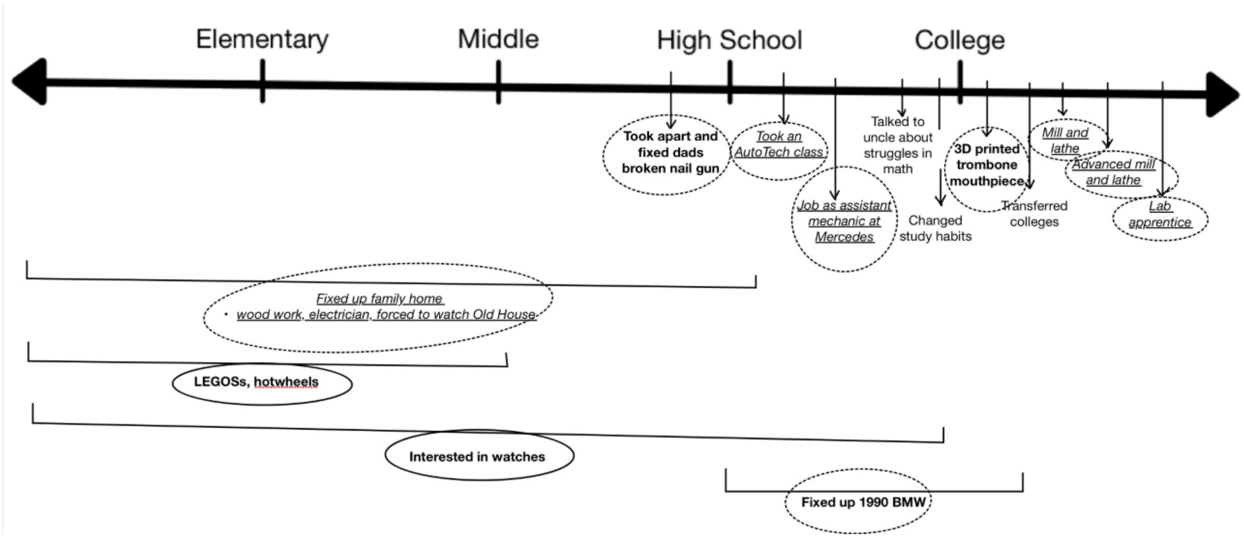

Figure 5: Example Timeline for Unstructured-Specific Pathway

The final pathway identified with the data set examined is unstructured-specific, and an example is provided in Figure 5. Here the unstructured nature of this pathway indicates that many activities were voluntary, but also, self-directed. Many activities from this pathway are undertaken to gain more knowledge within a certain area. The participant in the timeline shown in Figure 5, has used their own knowledge and skills to start their own projects such as fixing their father's broken nail gun or 3D printing plastic mouthpieces for his and his friends' trombones. Activities such as taking an AutoTech class or fixing up an old BMW embody specific exploration because a desired outcome was expected before beginning each.

6. Conclusions

The four pathways identified from the research provide a basis for understanding the different ways students become interested and engaged in STEM, specifically an engineering program with a significant making component. For each of these students, this interest and engagement was significant enough for them to declare a major in engineering. Examining timelines of these engineering students highlights the idea that each students' experiences related to STEM pre-college had led to their perception of "success" in achieving their collegiate aspirations. Looking at the experiences from two distinct dimensions such as structure and curiosity speaks to the complexity of codifying and measuring concepts such as motivation and interest, while overlaying these two dimensions provides a narrower means of examining the timelines of post-secondary STEM students.

We believe that this work gives insights into how the makeup of certain activities might affect that decision but also begins to address the idea of the importance of recognizing and utilizing state curiosity during K-12 activities. For example, *what meaning may be derived from the absence of structured-diversive in this population of engineering students who self-identify as makers?*

Limitations to these findings exist. The participants interviewed for this study represent a small minority within STEM disciplines, as they are all engineering majors. Additionally, our research focus is on student-makers, and as a result, all participants attend a making and design centric university and self-identify as makers. This biased sample might indicate why their K-12 experiences contained many making focused activities. Another limitation which could also become the subject of further research is in the appropriateness of using such a binary scale to define curiosity. For these reasons, it is imperative to note that any definitive findings from this research and this data set cannot be interpreted as representative as a larger body of engineers before further exploration and validation of the matrix is complete. Prescriptive recommendations for the types of activities offered are reserved until such a time where a larger sample size with a more targeted approach for the constructs of structure and curiosity can be used.

Our future work will focus on exploring pre-college experiences more broadly across STEM majors at this same mid-Atlantic University using semi-structured interviews and student focus groups.

Acknowledgements

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