Structure versus Curiosity: Developing a model for understanding undergraduate students' childhood pathways into engineering

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This study seeks to further develop an emergent model of students' pre-college pathways into engineering. In our previous research with student makers, four pathways were identified based on the nature of how pre-college activities were structured and the curiosity associated with engagement in the activity: structured-specific, structured-diversive, unstructured-diversive, and unstructured-specific. In pathways characterized by 'unstructured' activities, individuals identified that activities in which they engaged were performed with a great deal of autonomy in both how and what was explored. 'Structured' activities are those where the individuals did not self-impose or seek out the activity; activities were instead laid out by a mentor or expert. 'Specific' curiosity is where a clear path towards a specified outcome was clearly viewable by the individual creating, and 'diversive' curiosity is where activities are completed for the pure exploration or interest with no identified outcome. Three of these four pathways were identified in the first data set, while evidence of structured-diversive was missing. The absence of the structured-diversive pathway was hypothesized to be a result of the previous population interviewed rather than its absence among pre-college individuals.

In this follow up study, a series of seven 60–90-minute interviews with undergraduate engineering students were conducted discussing significant events encouraging students to major in engineering. Interviewees were asked to construct a written timeline of major events that impacted their pathways into engineering, starting with their earliest childhood memories. The timelines were then used as artifacts from which participants discussed those experiences as major turning points on their journey to engineering. Interviews thus focused on the "who," "what" and "where" of each major event in their timeline. Purposeful sampling was used in this study to ensure inclusion of home-schooled student populations as well as public and private educational pathways. Our qualitative analysis of the interviews indicates the presence of all four pathways. All results taken together demonstrate how understanding individuals' experiences through early childhood and high school can evolve or stagnate with age and development.

1. Introduction

It is the unique experiences and perceptions of an individual which develop personal identity; often each of those experiences are heavily influenced by others surrounding us [1-2]. One's choice in a college, or major, or even a particular career path is shaped by both positive and negative perceptions of prior experiences, often emerging from passions or interests developed throughout childhood [3]. Perception is a subjective evaluation of these experiences, and thus, positive and negative experiences differ from person to person. The positive experiences of college students majoring in engineering, despite varied and unique childhoods, can be classified to provide insights into the pathways students take to arrive in a STEM discipline. The development of interest in STEM in early childhood has been a high priority item for many schools and government initiatives over the past few decades introducing new curricular, co-curricular, and community programs alike, each of these programs fundamentally introduces STEM topics in different ways, although the structures and overall goals of them change. The diversity of these programs mirrors the potential diversity of students majoring in STEM, targeting underrepresented populations of students by offering a wide array of options for exposure and involvement [4].

Two types of learning arrangements, structured and unstructured, as well as two forms of curiosity, specific and diversive, have been previously identified and expressed as a matrix [5]. Students' pathways provide insight into the overlapping experiences of learning in *formal* educational settings as well *informal* settings such as the home. Towards the exploration of the complex definition and validation of this model, seven targeted interviews were conducted with students enrolled in a non-disciplinary engineering program at a mid-Atlantic, primarily undergraduate, comprehensive, public university. Exploring in detail the unique lived experiences of each of these students gives insight into the development of interest in STEM throughout their K-12 timelines prior to the decision to obtain an engineering degree.

2. Background

When examining the pathways of engineering students through their K-12 timelines, it becomes necessary to understand the types of influences present and the impact of the noted influences. Inclusionary practices in STEM have been a topic of great interest, with an increase in research and activities completed from the perspective of diversity, equity, and inclusion [6]. Historically, gender and race have been primary targets of these initiatives seeking increased diversity in historically White-male dominated spaces; just 21.9% of undergraduate engineering students identify as female and 17.1% identify as non-White [7]. Examining gender expression from a young age, such as gendered toys, has shown the preferences and expectations can be imparted on a young child through implicit means and actions [8]. Just as gendered activities and family conversations have helped shape a person's interest and pathways, there exist other forms and ways a person develops interest or becomes exposed to a certain topic. For STEM or any educational-type of interest, there exists some additional important factors to be able to recognize and consider, like more broadly examining the impact of familial socialization, the educational setting in which a student is involved, co-curricular and extracurricular opportunities available to a student, among others [9-11]. These factors may also be influenced by demographics including social status or geographic region [12, 13].

Engineering identity has been defined in many ways ranging from personal to external perceptions of oneself as an engineer or even one's expectations of success or affections to engineering [14]. Measuring engineering identity is accompanied by similar challenges of evasiveness, but some attempts have included quantifying students' interests, feelings of recognition and their confidence in areas related to engineering [15]. In one study on engineering identity, Gee affirms that an engineering identity requires active participation and socialization from others for development [16], and possessing an engineering identity is noted as leading to increased retention in higher education and future success within the engineering field [17]. Although most work tends to focus on the development and role of engineering identity in higher educational settings, entities such as the U.S. Department of Education and the National Academies Press have discussed the importance of recognizing the impact of developing an engineering identity in K-12 to enhance students' interest in STEM [18- 19]. A combination of factors, discussed below, influence a student's knowledge regarding STEM and thus provide the opportunity through socialization methods and activities to develop an engineering identity.

2.1 Family and Peer Socialization

Parental socialization refers to the influence of a parent on their children generally to enhance the development of desirable traits needed for adulthood and conformance to social norms [20]. Parental socialization has been found to have both short-term and long-term impacts on the psychosocial development of children [21]. Family socialization includes the influence of family on things beyond societal norms including interests and occupations. Studies on occupational inheritance have found that paternal occupation and education increases the chances of higher education for their children [22-23]. Specifically in careers related to science, researchers Halim et al. found that increased opportunities for children provided by parents facilitate scientific exploration promoting science careers in the future [9]. Further research into family socialization within STEM has focused on both opportunities provided to children by parents as well as perceptions provided by parents as being key influences on children's future career trajectories [24].

The presence of role models in a child's life have been linked to influencing occupational decisions [25]. Mentors come in a variety of forms for adolescents, but none are more influential, especially to career choice than parents [26]. One study looking at the effect of parents on one's future career as an engineer, specifically a mother's career, found high influence toward similar career paths [27]. Surrounding a child to a particular occupation through conversations, activities, and even visits to occupational sites increases a child's understanding of that occupation [28]. Further, this occupational socialization increases a child's capital through increased knowledge of the occupation, awareness of occupation-related activities, and insight into occupation-specific jargon [28].

Peer influence is a well-researched area in the development of adolescents, particularly in the negative effects of peer pressure [29], though there does exist the potential for positive peer influence as well; for example, peers joining school clubs together leads to motivation and increased engagement in academics as related to the views of a peer group [30]. Further, Tey et al., found that friends have an influence on future career paths into STEM [31]. Termed 'peer exposure', it was also found that females tended to prefer STEM activities if they perceived other females enjoying those same STEM activities [32]. Having different interests and being involved in different clubs, a friend can help expand the available opportunities for another friend and makes it feel less unknown. We have seen similar with student engagement in makerspaces; young women tend to follow friends into makerspaces increasing engagement through repeated exposure, knowledge, and awareness; this peer exposure overtime builds social capital [33].

2.2 Educational Setting

After the influences of family and friends, educational settings prior to college may be the next most influential factor in students' pathways into STEM. But often, these factors commingle; for example, while affluent families may opt for a private school, well-off middle-class and working-class families may exercise choice via where they choose to live [34]. Resources and opportunities available at local public schools vary greatly with the interplay of socioeconomic, racial-ethnic, and geographic status, and often metrics like standardized test scores fail to comprehensively quantify effects through comparison [35]. Further, policies on educational standards and even the definition of STEM education vary state-to-state [36]. Currently, 78% of states motivate STEM education in K-12 as for purposes related to the future workforce and economic development [36]. Many states, at least in some capacity, have introduced magnet STEM schools, providing a focused learning track for students within the public educational system [37-38]. Only a handful of states like California, Florida, and Texas, have increased the capacity of these STEM magnet schools to become a normalized option for any student once entering the high school level [37].

Over the past few years, the percentage of students being homeschooled has increased steadily, with a sharp increase notable after the COVID-19 pandemic in 2020 [39]. In Virginia, the number of students being homeschooled raised over 56% after 2019 [40]. In 2007, analyzed responses of parents found some reasons for homeschooling one's children include a desire to play an active constructivist role, to foster a strong sense of efficacy for learning, and to create positive perceptions of life context [41-42]. For STEM in particular, parents introduce interdisciplinary topics in a variety of ways supported by the flexibility in homeschool programming, like local cooperatives, online classes, local clubs, and STEM-focused museums [43].

Extra- and co-curricular activities complement traditional schooling activities in both formal and informal spaces. Sheridan et al. uses learning arrangements to describe the compositions of these activities, recognizing solo projects, collaborative group projects, equipment training, as labels to various making activities [44]. Studies have indicated the importance of students' involvement in STEM activities outside of school in developing a future interest in STEM [45]. More specifically, it has been found that while females tend to be more attracted to STEM through school-related activities, males prefer outside-of-school activities [46]. Over 65% of students acknowledge an interest in STEM before middle school age, yet often formal STEM programming is not part of the curriculum until high school [46]. Policies and interventions being focused on this older student population have given rise to informal educational spaces, for example, museums, camps, and science fairs, being available to a wider age range of people [47]. These informal educational spaces provide participants with authentic, hands-on, interactive learning, prior to more formal introductions, and it is believed that these informal spaces appeal to a more diverse group of people [47].

2.3 Gender Socialization

Gendered messaging manifests in many implicit ways such as relationships with parents, familial responsibilities, and even physical spaces [48]. This gender socialization begins at an early age with things like gender-associated colors or gendered-toys, leading to preference choices and interests later in life [49]. Studies analyzing gendered toys have found that boys' toys focus on subject matter like technology or action, while girls' toys focus on topics like care [50]. This early exposure to gendered occupational roles may then relate directly to the learning children engage in and their future educational interests. In STEM and engineering, the gender disparity between males and females is well documented [51]. Yet despite increased efforts to attract women, as of 2021, women only occupied 14% of the total student population within engineering disciplines [52]. To address this, there are now countless efforts to expand exposure to STEM for girls and young women through events, organizations, and diversity initiatives [53].

3. Research Questions

This project was guided by the following research questions. These questions were developed based on noted gaps in the initial model generated in earlier research [5]. Specifically, the authors sought to understand the different types of activities present and the drivers to engage in those activities in pathways of young men and women currently studying engineering.

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 were collected using semi-structured interviews of students enrolled in a general engineering program within a Mid-Atlantic University. Seven students were interviewed by a senior, undergraduate, White woman student enrolled in the same engineering program at the same university. In addition to engineering, the interviewer is working towards minors in honors interdisciplinary studies and mathematics. The interviewer considers herself to be an insider in the community studied. The interviewer used her personal network within the engineering program to identify students to interview. The study was reviewed and approved by the university's Institutional Review Board (IRB).

Using purposive network sampling, participants in the study were recruited among engineering students. Students were selected based on their educational background with a goal of identifying students who might challenge our previously developed model [5]. Of the seven students interviewed, five students identified as women. Two students were sophomores at the time of the interview; two students were juniors, and the remaining three were seniors. Two of the seven students self-identified as part of a racial or ethnic minority; the remainder identified as White.

Each of these seven students participated in one 60–90-minute semi-structured interview [54-55]. Interviews were designed to create a space for the participants to reflect on their K-12 experiences and how those K-12 experiences influenced their decision to major in engineering. The first three student participants were interviewed in-person in a private office on the university campus. The remaining four students were interviewed via Zoom. As a first step to the interview, all participants were asked to develop a timeline of their formative experiences leading to becoming an engineering major. Timelines were developed initially by students at the beginning of the interview prior to being asked questions. These timelines were then further developed based on participant-described activities throughout the remainder of the interview. 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. The timeline activity and interview questions are provided as an Appendix.

Data analysis followed an abductive process outlined by Tracy [56]. During the data immersion phase, the researcher began by reviewing the transcribed interviews while listening to interviews and adjusting the transcripts as needed for accuracy. Timelines acted as visual maps for the analysis process and acted as a secondary source of data. Analytical memos were created to keep note of important details or themes for each interview.

Identification of the four major identified themes was done by use of overlaid color coding by hand on each of the seven timelines using an *a priori* coding scheme. The activity types were grouped into structured and unstructured based on the definition and meanings identified through the previous interview set and subsequent analysis [5]. Then, the two types of curiosity were coded, allowing us to identify four distinct pathways found among the interviewee's experiences. Using the transcribed interview and the initial timelines as a guide, activities specifically noted without prompting by the interviewee was noted. 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. Findings

Our previously identified model [5] acknowledged the existence of four different types of STEM activities that are present on the K-12 timelines of students majoring in engineering: structured-specific, structured-diversive, unstructured-specific, unstructured-diversive. No additional activity types were explicitly noted in this follow up study.

Our findings are organized as follows: The emergent model with definitions of each activity and noted attributes for each activity type is provided as Section 5.1. Emergent understandings of each activity are provided as Section 5.2, and how these activities are noted to manifest for our varied interviewees is described in Section 5.3.

5.1 The Model

Undergraduate students' timelines of their K-12 pathways to their undergraduate major in engineering were characterized by a dominance in one of these four approaches to early STEM activities. These four pathways, with the definitions and attributes are Table 1.

Newly evident from the seven interviews conducted to validate this model, is that instead of existing as four distinct quadrants, activities exist more in an overlapping and interconnecting manner. This is to say that K-12 STEM activities are generally more complex and layered, then the original model conveyed. This complexity, as later illustrated through exemplars from the interviews, may not be intended but rather the result of the students' autonomy through participation or their perception during engagement. This complexity in activities leads directly to more complexity in the identified pathways. It seems naive to believe that any one person during the entirety of their childhood experienced only one of these four types, which was addressed previously by looking for domination of these activities throughout the entire timeline. Instead, it has become clear that the amount of any one activity is not as influential to determining the pathway as the amount of another activity, or part of an activity, that an engineering student has specifically recalled as memorable and important.

Table 1: Descriptions and attributes of four activity types

Name	Definition	Attributes
Structured-Specific	Activities in which a particular outcome or piece of knowledge needs to be obtained through an activity that is facilitated by someone.	Organized, deliberate, systematic, attentive, enjoys routine
Structured-Diversive	Activities in which an outside mentor facilitated an activity in order to be immersed in an activity because it is new and interesting to them.	Flexible, explorative, multimodal, self-advocating
Unstructured-Specific	Activities completed solo for the purpose to gain knowledge in a particular area or skill set.	Focused, independent, goal-oriented, disciplined, purposeful
Unstructured-Diversive	Activities in which the person of interest is also the facilitator seeking stimuli from engaging in the activity.	Adventurous, creative, open-ended, inquisitive, inventive

In the second set of interviews, asking students to first create a timeline of the activities they remember and feel is important to discuss followed by probing and follow up questions, reveals both the perception of those memorable events as well as recall of more nuanced details of those events. These secondary activities remembered, although present on their timeline and therefore helping shape a path forward into a STEM major by providing additional opportunities, do not seem to have as much influence on why students found enjoyment in these activities, nor do they reveal why students continued to take advantage of those opportunities and engage further in STEM activities up to their declaration of engineering as their college major.

5.2 Categories of Pre-College STEM Activities

Structured-Specific Activities are characterized by rigidity, focus, and goal-oriented tasks; use of developed curriculum, curated topics, offered courses and classes which allow one to learn desired content are exemplar activities. As an example, consider the following described by an interviewee: “I wanted to explore woodshop, and so I talked to my new school, and they had a woodshop class. [Taking it] was a choice because I wanted to learn more about it.” For this student, a goal of learning to work with wood and an available woodshop class came together to meet the desire. Like many of the other quadrants, underlying motivations and interests play a large role in the determination of identifying structured-specific activities. Noting that a person is actively seeking to learn that material is a clue; this characteristic is shared with unstructured-specific. Though what distinguishes the two types of activities is how the individual chooses to learn: curated content matches to structured, while open exploration characterizes unstructured.

Structured-Diversive Activities are taken by individuals seeking to learn broadly about many topics across a wide variety of spaces. The activities, though, are similar in-kind to structured specific: developed curriculum, curated topics, offered courses and classes. Often, with structured-diversive activities, a mentor or supervisor facilitates a supportive, but hands-off, learning spaces giving freedom to express curiosity that is unconstrained by a specific task. As an example, consider the role of the teacher in this described Project Lead the Way course "[the] teacher left you pretty independent unless you came to them with questions. And then they would [do that] engineering teacher thing, where they answer your question with more questions to make you think." For this student, the learning activities occurred in a formal course, but the teacher provided exploratory space for inquiry and curiosity allowing the student to follow their own intuitions.

Unstructured-Specific Activities are those that are exploratory, covering a wide-breadth of related subjects but remaining concentrated towards a single goal. Engagement in unstructured-specific activities is characterized by high self-motivation and high self-efficacy. For these activities, sometimes people engage to learn a task, while in others, engagement is driven by a fixed-mindset: their mind was set on independent task completion. For example, one student reflected on how he approaches working on his car in high school in this manner, saying, "I'd be like, all right, I'm going to try and identify the problem. I'm going to try and look at a video, see how to do it." Here we see that the activity was focused, goal-oriented, and driven by one's self.

A noted difference between unstructured-specific and structured-specific, is in the type of activities; with unstructured activities, the tasks noted in our research tended to be small and less complex with readily accessible information, and when the unstructured-specific orientation is for too complex of a task, frustration was noted: "I would sit around for like, an obnoxious amount of time sometimes trying to learn how to do it, and I'd get it done." Here the interviewee was noting their persistence led them to keep trying, but without achieving results.

Unstructured-Diversive Activities are often characterized by crafting, making, imaginary and pretend play; an activity defined as "the acting out of stories which involve multiple perspectives and the playful manipulation of ideas and emotions" [57]. Interviewees note periods in their childhood characterized by either independent or codependent activity where the use of creativity and curiosity allow recreation of the world as they envisioned it whether based on their real-life experiences or their perception. For example, one engineering student, who is a twin, talked about her relationship with her sister as they played when they were younger compared to the rest of her family, "I guess having another, 4-year-old to play with made it better. I guess [our parents], they couldn't see the vision." Here we note the activity of play between siblings, but also, central to this dynamic is that no one involved was attempting to control the situation, instead it was mutually exploited by all parties, still maintaining that unstructured nature without complete independence. This same student later talks about how she and her sister used objects around the house to compliment the world they created, describing how she would "use blankets because I would like to build houses for my toys. And then it would be like our own world."

After early childhood, unstructured-diversive activities manifest more in crafting-type activities rather than pretend play. For example, one interviewee stated, “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.” Here we note this continuation of creative engagement through hands-on activities and making; through these examples is a notable transition from creative play to physical building and making, which are often associated with engineering [58].

5.3 Pathways into engineering

Seven engineering students were interviewed, each of whom have different demographic information, educational experiences in various settings, family with various interests and experiences and their own personal interests developed through the interaction of these many aspects. Adherent to the original model, some student’s pathways had a mixture of activities which consisted primarily within a single quadrant for a specific period of time before evolving like in Figures 2 and 4. Other pathways mixed activities and types between quadrants evenly throughout the entire timeline, shown in Figure 3. Three interviewees’ timelines into engineering are illustrated below as representative examples of pathways throughout this section. Each timeline has been reproduced and is color-coded to correspond to a visual representation of our model provided as Figure 1 for reference. Figure 1 expands the previous model to exemplify the transition between more static individualized activities to entire dynamic pathways representing all the influential experiences of a student which combine and merge to create the distinctive overlaps in the model. It is important to note that the overlapping character of these four-types of activities is reflected in the students’ timelines and is what is being captured by overlaps within the model; not all overlapping regions have been identified in the dataset.

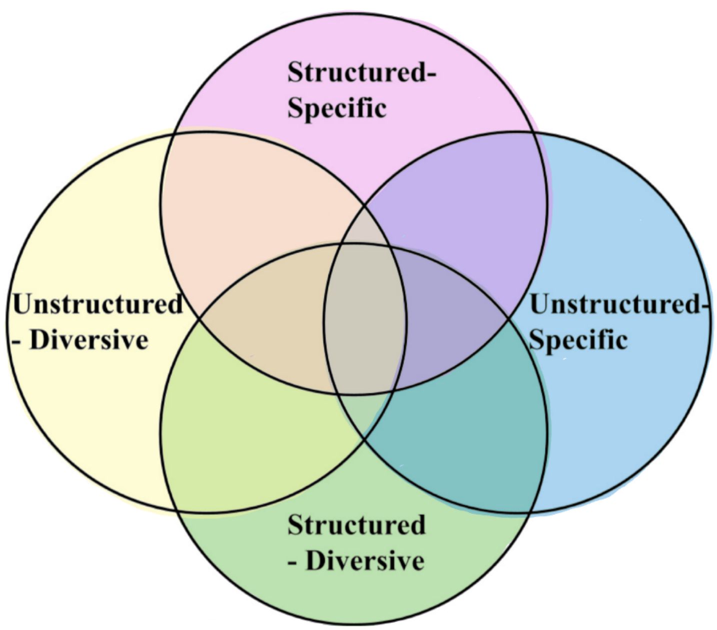

Figure 1: Model of four pathways

Of the five women students interviewed, four of the students revealed that the first experience that sparked their interest in engineering did not happen until late adolescence, either in eighth grade or in high school. As shown in Figure 2, this student started her timeline at eighth grade without leaving any additional room for experiences prior.

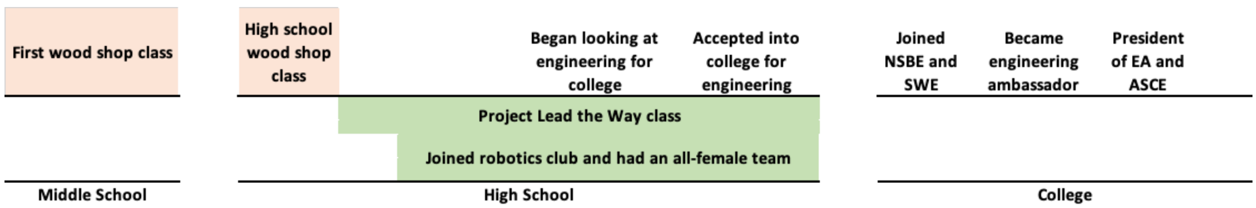

Figure 2: Timeline from interview with woman engineering student of relevant K-12 activities (colors correspond to Venn diagram in Figure 1)

Two of the women students both lacked people they knew personally who were engineers, and therefore, limited familial and peer socialization related to engineering in their early years seen in other interviewees who had those relationships. They were, however, presented with the opportunity to learn about engineering through their educational settings. Starting later in their childhood, both of these students began along the pathway of structured-specific, as they were forced to participate in STEM activities in school. After finding an interest for these types of activities, they sought out additional opportunities by listening to the suggestions of teachers acting as mentors; this ultimately gave them a choice into what they engaged leading them down a pathway of structured-diversive. This transition between the two pathways is exemplified through the passage below, as their experience and confidence increased.

> *So, with Project Lead the Way…because I liked woodshop so much at the time and the woodshop class was only one course. Like I didn't have a Woodshop 2, 3 and 4 [to take afterwards]. It was just that one woodshop class, and you're done. But my professor saw that I was interested, and I told him. I was interested in learning more about it and so he suggested me for Project Lead the Way, which was an introduction to engineering courses. And so, I didn't really want to do any of the other electives, like music or home economics, so I was like, 'Okay, I'll try it, and see what it's like'. So, I took those classes my sophomore year of high school up to my senior year.*

On this timeline, the first activity is a wood shop class, and similarly, the other four women students with comparable timelines also had their first listed experience as a structured activity initiated through a formal school setting. Two of the students graduated from a classroom setting to a more informal one. The description of these types of electives or extra-curricular activities from the students, like the one below, led to a classification of a structured-diversive activity.

> *[I enjoyed] everything [about the class]. I would... for me, I was open to learning something new all the time' I didn't really have any constraints on what I did or didn't like, I was just open to learning about it. So that is mostly what I enjoyed about that class was just learning a bunch of new stuff in there, every week was different in that class. Whereas, in other classes… it's like art, it's a continuation of drawing but a different type of drawing. Whereas in this Project Lead the Way class, we talk about learning like*

mechanical engineering, or electrical engineering, or something else in terms of engineering.

The key characteristics of this description is partly the presence of a teacher who acted as a mentor adding guidance, but also how the student talks about the vast opportunity for exploration through this class. She explicitly mentions that she enjoyed the openness and the breadth of information covered by looking at different disciplines of engineering. This shift from specific curiosity expressed in formal classrooms to diverse is indicative of how these students took their initial interest in STEM and wanted to find more things that interested them by learning about a vast variety of STEM-related things to find additional interests. The two students did not note a significant difference in the relative importance in the structured-specific to structured-diversive activities to their overall pathway into engineering, indicating that despite actively searching to learn new things, the students valued having that initial gateway through mandatory classes.

The fifth woman identified significant events in her timeline much earlier than the other four women.

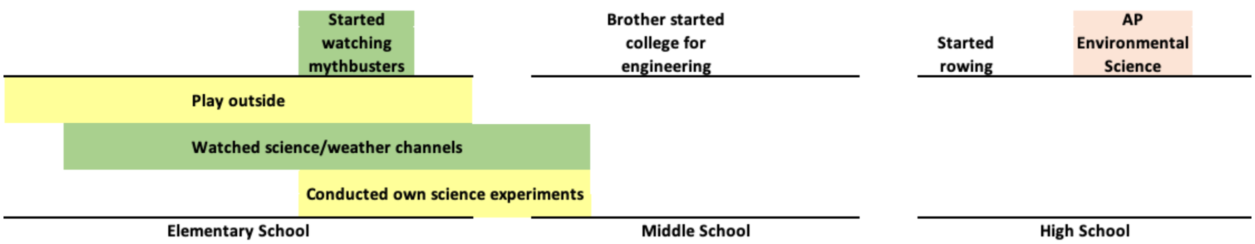

Figure 3: Timeline from interview with woman engineering student of relevant K-12 activities (colors correspond to Venn diagram in Figure 1)

Though she similarly had parents who did not have technical or extensive knowledge in engineering, she had parental socialization into STEM through her father who would watch scientific shows that she clearly recognized as important to her pathway. After watching these shows, she would routinely mimic the procedure for some of the experiments she watched in real life based on questions she had.

Yeah, I remember one distinctly, yes. It's so embarrassing because I had no direction, but I did. I had a thought that I knew what bacteria was, right? [But I] did not understand the process of how long it takes or something. I was like, 'Well, I think Legos are really gross, right? What if I lick this Lego, and I put it on this toilet that's gross or something, and I tape it, and I wait 8 hours, and I wonder what's going to happen. I remember doing that because I was watching Mythbusters. I put that there, and I just wanted to see what would happen.

Did anything happen?

No. I kind of went back and my mom was like, 'why is there a Lego taped to the toilet seat?' I said, 'Wait, I know something's going to happen.' Nothing happened. It was just a wet Lego. So yeah, that was my one experience that I can remember.

This student's timeline has a heavy focus on diversive activities, as she was performing open-ended experiments with no specific goal in mind other than to try to make sense of her experiences and observations. Yet, throughout her timeline, the experiences were arranged in both structured and unstructured ways. The experiments she ran by herself were clearly self-initiated, but she simultaneously reflects on how she would run the experiments because of watching the *Mythbusters* show which her father would turn on the TV for himself and his kids to watch.

> *He liked [science shows], but he also thought it was more beneficial than watching Dance Mo's. That's a confirmed quote from him. So he would put that on, and I would say around 10 [years old], Mythbusters. In this [timeframe], there was a lot of TV exposure…*
>
> *What was cool about it?*
>
> *I think what I thought was cool about it was that, at least to my knowledge, no one else was doing these experiments, and they were having fun with it. So I saw that they had a lot of logic, and they were able to make an experiment really well, but they still had fun, and they still could, make things explode, which is something that I never really saw firsthand or anything. But also sometimes they didn't make things explode. With Rose on the Titanic or something, they tested it, o' they tested being in cages and stuff. I thought it was nontraditional from the kind of experiments that I thought of in my head. I guess when I was little, I thought regular experiments were like getting tubes and putting things in it and then waiting. But this was really hands-on and interactive and fun.*

This passage starts by her explaining how her father was the driving force behind her watching various science-related TV shows, but she also discusses how this morphed into her own interests in the shows. Her interests stem from how the shows covered unknown and mysterious topics in a way that caught her attention.

Both the men interviewed differed in their childhood in that they both had a direct family member who had an occupation in a STEM field, and thus, extensive parental socialization. One student had a mother who was a math teacher, while the other's father was an engineer. The student with the engineer as a father was unique in the fact that he was homeschooled.

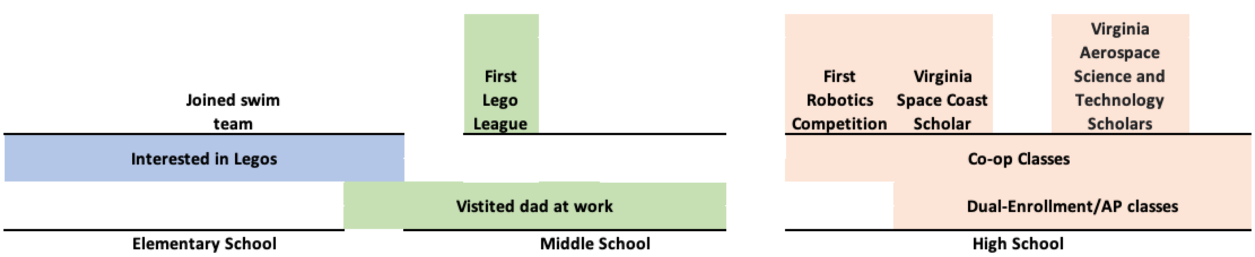

Figure 4: Timeline from interview with men engineering student of relevant K-12 activities (colors correspond to Venn diagram in Figure 1)

The student clearly identified experiences in early childhood, like building with Legos, as highly influential to his later pursuit of engineering. The types of activities this student participated in are common gendered experiences related to building and physical manipulation for boys [35]. He would often work with his brother or father to build different structures and noted he would try to challenge himself by trying to achieve different outcomes with the Legos.

> *The train set would generally be used for like a couple of days and then disassembled because generally I'd have, different sets of criteria of like, 'okay, I'll take all the elements and make it as compact as possible', or 'take all the elements and stretch it as far out as possible'.*

It is through a description like this that the intersection between unstructured-specific and unstructured-diversive becomes clear. A child playing alone with Legos can either be building for the enjoyment of creating, and thus, have no desired direction, or as the student above does, a child can have a certain desired outcome. The latter requires a level of discipline and understanding most younger children do not possess, but even as this student noted, he used Legos as a creative outlet well into his middle school and high school years, eventually becoming involved in various Lego robotics competitions.

The student then discussed a series of informal experiences, like clubs that he was involved in throughout childhood. He claimed his mother initially sought to put him in activities like this to socialize him, but chose the subject of the activities based on his interests. Both of his parents had active roles in these activities as well through organizing or mentoring roles, resulting in a highly structured pathway. Although the type of curiosity expressed could be either specific or diversive, the student described why he was interested in participating in the various competitions and routinely mentioned how although he would have to complete a wide array of STEM activities, he was only interested in learning more about a handful of them.

> *Honestly, I kind of wanted to build the Lego stuff' I wasn't the most interested in programming', I don't recall. Nor was I interested in the research project stuff. I just wanted to build the robot. And the programming stuff was out of necessity to make the robot actually move and stuff. I did actually end up liking that. So that was really good to get that program experience early. I think doing that also led me to do a little bit of side stuff like, Scratch. I did some side stuff with that just for fun, because there's another guy on my robotics team who would do that and make little computer games and stuff. So I did that too.*

As this student reflected on his past motivations, it is clear that the primary reasoning for participating in certain clubs was very distinct and identifiable. He joined this Lego robotics club because he enjoyed playing with Legos and explicitly wanted to build a robot and the steps to get to that outcome were not of initial interest to him. The combination of activities his parents signed him up for outside of homeschooling, coupled with this focus on his peculiar interests places him on a structured-specific pathway.

6. Discussion & Conclusion

Through our most recent interviews, we noted that for each of our participants there are intersections between the four types of activities, and while one person may favor an activity type at one point during their childhood, this trajectory is not absolute. This complexity results in the formation of more nuanced and comprehensive pathways, which are indicative of both a student's access to different activities, but also, the presence of individualized meaning developed through those various activities [59-60]. We see that people have multiple types or intersections of these four activities present in their timeline. Often though, one's timeline, despite this inherent breadth, has the most *influential* activities upon reflection dominating one of the four quadrants over time.

We did notice some interesting patterns. When we noted that students were introduced to self-directed STEM activities early in their childhood, we also noted more of these types of influential activities later in their childhood, while when we noted structure in early childhood, we also noted more branching of pathways. This aligns with other findings that show how early exposure to STEM-related activities generates a more positive disposition towards STEM and also prepares students for the more expansive opportunities available in middle and high school [61-63]. Also, for structured activities, personal and identified interest in an activity appears to be more important than the type of activity or even its otherwise intended purpose. Hanauer et al. similarly noted that project ownership developed through things like personal agency, personal significance, and mentorship have been linked to increased persistence through STEM [64-65]. This means that for our interviewees, interpretation was theirs to identify and develop rather something that could be prescribed.

The role of external role models, family, friends, and peers, is noted throughout the narratives as an essential aspect of socialization and introductions to STEM and engineering, but perhaps most important for all of our interviewees was the role of parents [41,44]. Through parental socialization, our interviewees were exposed to informal spaces and co-curricular activities, and critically, this exposure did not require the interviewee to overcome obstacles or barriers, especially when involvement wasn't burdened by a tangible learning outcome [66].

Once students enter high school, when there is a wide array of the types of activities, students have the choice to participate in the ones that generate the most interest and enjoyment for them. Otherwise, with a sustained participation in STEM, students engage in the opportunities presented to them. Once in college, the number and type of activities expands as well as the students' agency for choosing activities which is when they are able to differentiate between the intricacies of engineering. Students, all of whom share the title of engineering student, identify a variety of reasons for enjoying the major. And perhaps most interesting, all interviewees identified different aspects of engineering they enjoyed most as matching to types of activities they did in childhood.

It is clear that there is not one pathway into STEM, but our results do point to some important features which seem to provide young people more capital that can ease their pathways into engineering. It was rare within all the interviews conducted and timelines developed to find students whose pathways consisted of purely one single type of activity, instead it became obvious that the students who became successful and excited about STEM were the students who had diverse exposures to a variety of activity types during K-12. We close with three recommendations: More and early varied STEM-related exposures to open young people up to later exposure through middle school and high school. More role models, especially when familial role models are not available, to provide young people with exposure to activities, language, and career paths associated with engineering and STEM providing early and important socialization. Finally, the availability of open and accessible structured activities cannot be underestimated in the development of young people's journeys. For some, these recommendations come easily, through schools, community centers, and family; for others, not so much. As a profession, we must recognize that inequities exist and fight to create pathways open to all potential students.

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Appendix: Interview Guide

<u>Activity: Creating a Timeline</u>
<u>Directions</u>: Start with poster board with line down the middle, participants will be given 10 minutes with a marker to note major events that impacted their pathway into engineering. Participants can begin adding events anywhere along the timeline and move through as they see fit

<u>Turning Point Interview:</u>
Using a series of probing questions, the moderator will walk the participant through the timeline and ask about each event and its importance. Participants may be asked to add sticky notes to the timeline to indicate additional information about the event.

<u>Probing/Follow-up Questions for Each Event on the Timeline</u>

- Event themselves
  - What were the important events, activities, etc.. that you did when you were younger? What age were you when that happened?
  - What were the important events, activities, etc.. that you did when you were in middle school?
  - What were the important events, activities, etc.. that you did when you were in high school?
  - What did you do at the event
- Who was at the event
  - Were you by yourself when you did this activity?
  - Did you complete any part of the activity by yourself?
  - What was the relationship like with the person you worked with?
  - How did the both of you use your knowledge for this activity?
  - How did you both construct knowledge during this activity?
- Where did the event take place
  - What was available in the space the activity took place?
- Motivation
  - Who was the one to first suggest this activity
  - Did you want to engage in this activity?
  - Why did you or did you not want to engage in this activity?
  - If not, why did you anyways?
- Outcomes
  - How did this activity end?
  - Was there a physical artifact as a result of this activity
  - What did you do with this artifact?
  - How did you feel after the activity ended?
- Over what period of time did this activity take place?
- Wrap up Questions
  - Following this conversation about your timeline did you feel were the most important factors in your decision to major in engineering?
  - At which point in your timeline did you know you wanted to be an engineer?
  - What do you most enjoy about engineering?