



Observing and Measuring Interest Development Among High School Students in an Out-of-School Robotics Competition

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Within the last decade the number of out-of-school STEM learning programs available to school age youth has drastically increased¹. Many of these programs were developed with the intent to address the well-documented need for increased interest among K-12 students to pursue STEM related fields as adults². With the proliferation of out-of-school STEM opportunities comes the need for evaluating their effectiveness in developing and maintaining interest in STEM, as well as establishing guidelines for future program development. To provide this practical guidance to program developers, it is particularly important to understand how the actual mechanism of interest development is supported by the learning environment of an effective out-of-school program. Several methodological approaches exist to assess interest and its development, including: self-report surveys, short and long term retrospective interviews, and *in situ* observation. However, interest researchers recommend a combination, or triangulation, of these measures in order to create a robust and comprehensive understanding of interest as it develops over time³. In other words, it is critical to evaluate both *if* a program is effective and *why* the program is effective.

This paper presents findings from a seven-month-long exploratory study employing mixed methods research for assessing interest development among high school aged students in the FIRST Robotics Competition (FRC), an out-of-school robotics competition. Our three primary goals are: 1) (theoretical) add to and support existing literature in interest development and socio-cultural learning; 2) (empirical) further the evidence based connections between interest development and social cultural learning theories; 3) (practical) contribute guidelines and recommendations to program managers and developers on designing out-of-school learning environments that promote interest in engineering. The practical goal of this work is to provide contributions based on our findings for out-of-school program managers and developers who wish to increase student interest in engineering through their programming and training of staff, mentors, coaches or teachers. The theoretical goal is to add an in-depth description of the mechanism of interest development in the context of out-of-school engineering to existing literature, and to strengthen the connection between socio-cultural studies of learning and more traditional interest development research.

As Azevedo⁴ recommends, we have chosen to examine interest development in an out-of-school context in order to understand the process without the constraints afforded by traditional classrooms. In this environment, students engage voluntarily, and are free to participate as frequently and intensely as they choose. It is our hope that by observing how high school aged students *organically* organize themselves based on their common interest in robotics and engineering that we will be able to uncover facets of development that may not exist while confined in a classroom. This approach requires grounding our analysis in both interest development research as well as models of socio-cultural learning.

1.0 Theoretical Framework

We begin by introducing two theoretical models to support our analysis. The first is the Four-Phase Model of Interest Development (FPMID), which conceptualizes interest as a psychological state and a predisposition to reengage domain content⁵. This theory proposes four phases of development that are defined by varying levels of positive feelings, value, and knowledge. The second theoretical model is Lave and Wegner's⁶ Situated Learning, a socio-cultural approach, which sees all learning as enculturation into a *community of practice*. These two theories provide complimentary approaches for analyzing the development of interest within a social out-of-school context⁷, and this multifaceted view will allow for a rich description of the mechanisms by which interest is developed and maintained⁵. We proceed with an introduction to each theory, followed by a detail of how these two distinct theories can be interwoven for deeper understanding of the phenomena being studied.

1.1 The Four-Phase Model of Interest Development

The FPMID is based on a few well-established fundamental conceptualizations from contemporary interest research. First, the FPMID is a person-object theory, which describes interest as an enduring and dynamic relationship between a person and a specific object or *domain*^{8,9,10}, which includes the knowledge, artifacts, norms, and practices of the community affiliated with the domain in question (e.g., historians, engineers). In this view, interest is a dynamic relationship between a person and their social and physical environment¹¹. The second fundamental concept is that this relationship has both cognitive and affective components^{11,12,3}. Generally, the affective component is described in terms of positive feelings and the cognitive aspect in terms of personal value of the domain. However, a feature of the FPMID that distinguishes it from other interest development theories is the inclusion of *domain knowledge*—knowledge of concepts, external representations, and skills that are central to achieving competence in the domain—as a crucial part of the cognitive aspect of interest development³. Thus, FPMID considers positive feelings, value and knowledge to be the key contributors to interest and to its subsequent development, or change with time and experience.

The FPMID follows much of modern interest development research in recognizing two distinct forms of interest: situational and individual. The first, *situational interest*, is a state briefly invoked by the environment, and is context-specific, impulsive, and transitory. The other, *individual interest*, or personal interest, is an individual predisposition to reengage with a domain and is context independent and enduring^{13,9,14}. In the FPMID, these two forms of interest are each further subdivided into two more specific classifications, to create four sequential and distinct phases⁵. The earliest of these phases, *triggered situational* interest may be very brief, and the individual may not even be aware of the trigger. This early phase is most heavily influenced by affect, or positive feelings^{5,10}, and needs support from the environment to continue¹¹. The second phase, *maintained situational* interest, is characterized by situational interest that is held and sustained over time. This phase of interest is also typically supported externally via activities and environments that induce a feeling of personal involvement and significance¹⁵, and is believed to form the foundation for developing individual interest⁵.

1.2 Emerging and Well-Developed Individual Interest

Much of the work of the current study focuses on the development and maintenance of the two phases of individual interest, and we therefore will commence with a more detailed description emphasizing the nuanced differences between the two. It is believed that, for a specific domain, repeated engagement that generates maintained situational interest may create a disposition to seek reengagement with that domain³. This transition is described as *emerging individual* interest, the third phase in the FPMID, and is characterized by an increase in stored knowledge and value for that domain⁵. At this phase, interest becomes more and more self-generated, relying less on triggers from the environment. However, support from the environment helps to sustain engagement and interest by enabling the development of knowledge and value in the domain. As knowledge and value deepen, so does the predisposition to engage with the domain, and this deeply entrenched interest is referred to as *well-developed individual* interest. In this fourth phase, interest is primarily self-sustained, engagement is resilient in the face of frustration, and can also endure over a long period of time. While positive feelings play an important role in both phases of individual interest, it is differences in stored knowledge and value that define the distinction between emerging and well-developed individual interest. Empirically driven descriptive characteristics of each phase of interest provide guidance for distinguishing between these two phases¹⁶.

Based on these descriptive characteristics, the difference between emerging and well-developed individual interest can be summarized as differences in levels of content engagement, need for external support, domain knowledge, personal value for knowledge of the domain, and perseverance in the face of difficulty or frustration. These indicators of individual interest can be used to distinguish between phases, and are valuable ways of operationalizing the development and maintenance of interest¹⁷. Scheifele¹⁰ is critical of Hidi & Renninger's emphasis on both knowledge and value development in determining individual interest, as he believes their model requires knowledge to develop before value because it is the gained knowledge that is valued. However, in the FPMID, Hidi & Renninger⁵ describe value and knowledge increases occurring simultaneously. In this view, gained knowledge helps to deepen value for the domain, but deepening value also drives the desire for greater knowledge. As these two cognitive factors increase, so does individual interest⁵. Increased knowledge and value may also be the driving force behind increased engagement with the content of a domain, and the decrease in the need for external support¹¹. Persons with increased value for a domain and a desire for knowledge will seek opportunities to develop that knowledge, and then continue to seek engagement in order to apply that knowledge and satisfy their value of the domain⁹. Thus, increases in knowledge and value also increase the desire for engagement¹⁸.

In contrast, early on in knowledge and value development, persons need support in learning the customs, culture and understandings that define a domain. Their lack of knowledge and experience can make it difficult to generate their own curiosity questions¹⁹, find resources to wrestle with challenges⁷, measure their work against what is already known⁵, and effectively engage with others in the domain²⁰. Support from peers, mentors, and teachers, which can be seen as a type of scaffolding^{21,22}, assist with increasing stored knowledge and value^{7,16} and allow

relative novices or newcomers to engage in meaningful ways. As novices become more practiced they are able to fade these supports and drive much of their own learning, exploration and engagement²³. In this way they also acquire the resources to demonstrate greater perseverance in the face of frustration. Furthermore, a person may need critical early support for understanding how and why knowledge of this domain has value²⁴. This transition towards greater stored knowledge and value is what defines the evolution of an emerging individual interest into a well-developed individual interest and is the mechanism by which interest develops at higher levels^{5,16}. Thus, it is important that an in-depth study of the mechanism by which interest is developed, must include attention to the details of how a person is supported within and enculturated by members of existing communities of practice.

1.3 Situated Learning Theory: Legitimate Peripheral Participation

Understanding the generation of knowledge within a rich social and cultural context, such as an out-of-school robotics program, motivates our inclusion of a second theoretical lens: Lave and Wenger's⁶ situated learning is a socio-cultural perspective that describes all learning as legitimate peripheral participation (LPP) within a community of practice. By *community of practice*, Lave and Wenger⁶ interpret learning through participation as changes in one's engagement, social practices, and corresponding views and forms of self-identification. In this theory, all learning happens within a community of practice, LPP is their way of describing the method by which newcomers enculturate into the community, and more seasoned members achieve more central participatory roles and community influence. Through increased levels of participation, supported by *old-timers* – the more senior members of the community – newcomers slowly learn the skills, values, habits, and overall culture of the domain as they engage in authentic practices of the community²⁵. This type of authentic learning is documented more frequently in out-of-school settings than traditional classrooms⁷. Situated Learning Theory provides a useful perspective for analysis in this context.

The theory of situated learning was inspired by earlier work studying learning through traditional apprenticeships⁶, which were thought of as particularly concise examples of out-of-school learning. Lave and Wenger⁶ describes how apprenticed tailors in Liberia initially learn their craft by operating at the periphery of the central work of the master tailor. At the periphery, novices do little actual tailoring, but by observing others performing “legitimate” (i.e., authentic) work, novices gain an understanding of the whole process, such as how various steps of measuring, marking, cutting and sewing are integrated. After time, the apprentices are responsible for contributing small parts of the whole, under the supervision of the master tailor, such as sewing buttons and measuring lengths of cloth. They begin to move, metaphorically, from the extreme periphery, to a position a bit closer to the center. Later, they engage in more complex aspects of the task, such as assembling precut pieces, before they are finally given the responsibility of creating an entire piece of clothing from scratch. This early groundwork for describing learning in an authentic environment through legitimate peripheral participation became a model for providing more authentic and meaningful STEM learning opportunities for students both in and out of school.

These particular strategies for teaching have been re-described in the educational research literature as modeling, coaching and scaffolding^{26,27}. *Modeling* occurs when a task is performed by an expert or more-abled peer as a novice observes the process. In this way, an understanding of the practices of a community can be understood as a whole before fully engaging in any one part. The less salient aspects of what occurs in modeling can be vocalized in order to help convey what the expert is doing²⁸. *Coaching* can happen across all levels of participation. As the newcomer begins to do specific work within the community of practice, they are given feedback from old-timers in the form of hints, heuristics, assessment of mastery, or even physical assistance. *Scaffolding*, which can be seen as a specific method of coaching, refers to supports that a newcomer is given to accomplish tasks they would not otherwise be able to do. These types of support may also be evident in many out-of-school learning environments to support the growth of newcomers towards more full participation and status within a community of practice. It is our contention that Situated Learning is an effective way to describe how newcomers gain knowledge, values, and skill in a domain, and thus represents a mechanism for the maintenance and development of domain-specific interest.

1.4 A Socio-Cultural Perspective on STEM Interest Development

While the role of the environment is present in all theories of interest development, interest research often does not consider interest development through a socio-cultural lens²⁹. Research which does utilize a socio-cultural perspective to observe interest development includes focusing on the role of the social context on interest development³⁰, viewing interest development through the lens of a learning ecology^{7,31} and as part of an individual's lines of practice that are closely related to their environment⁴. These approaches inform our connection of the socio-cultural authentic learning environment that an individual is a part of and the development of that individual's interest in a domain. The FPMID recognizes the crucial connection between the individual and the social context, and earlier work by Renninger³² emphasizes this²⁹. Thus, the role of social organization to support the process of enculturating a newcomer to a community of practice is key to understanding the development of interest, and we believe a socio-cultural perspective such as LPP combined with the modern conceptualization of the FPMID to be an effective method of assessing interest development. With these two theories as a framework we pursue the following research question: How is student interest in engineering maintained and developed while participating in an out-of-school robotics competition?

2.0 Methods

In previous research, the authors³³ conducted a study designed to measure changes of interest for members of an FIRST Robotics Competition (FRC) team using a Likert-style survey that they developed for that purpose. The authors found a significant increase in the level of interest in engineering over time. Consistent with recommendations for conducting qualitative observational studies alongside quantitative studies, the first author spent numerous evenings during this earlier study with the team over several months in order to get a better sense for the club organization, and to establish rapport with the participants^{34,37}.

For this study, participants from the same FRC club team were recruited through their membership with FRC and observed for a period of 7 months while participating with the team. At the beginning of the study participants were asked to complete a pre-participation (pre-interest) survey to assess their initial level of interest. During the course of the study a total of 18.6 hours of video data of participant activity was collected over one-to-two-hour sessions at 14 team meetings and two days of the team's FRC regional competition event. After completion of the competition season, participants were asked to complete a post-participation (post-interest) survey to assess their interest level after the season, and they were then interviewed following a semi-structured protocol.

2.1 Participants and Setting

A total of 20 participants were recruited for the study, with 13 participants completing all stages of the study protocol. The seven participants who did not complete all stages were removed from analysis^a. Of the 13 remaining participants 10 were male, were of varying grades in school (freshman = 4, sophomore = 2, junior = 4, and senior = 3) and had varying years of participation in FIRST (1 yr. = 4, 2 yr. = 3, 3 yr. = 2, 4 yr. = 2, 5 yr. = 2). Participants attended five different area high schools: seven of those students went to the same school, three others attended a different school together, and the remaining three students were each enrolled in a school with no other team members. Six of the students had taken an AP science course and seven students had taken an engineering course prior to participation.

For this study we chose to observe students participating in FRC, because it is an out-of-school organization for high school students that is an excellent example of a rich context for investigating interest development in an authentic learning environment. In addition to the high school robotics competition, FIRST offers several other levels of competition, such as FIRST Lego League (FLL) for middle school students. As an organization, FIRST was created in order to “inspire young people's interest and participation in science and technology.”³⁵ The FRC competition is designed to engage students, who voluntarily participate, in an intensive engineering design competition over a three month season as well as team directed robotics and engineering activities throughout the rest of the academic year. During the FRC season, students, with guidance from their mentors, have six weeks to design, create, test and improve a competition robot, which will compete in a series of two-minute three (robots)-on-three (robots) matches at a regional competition. Each year of the competition, a novel game is introduced, marking the start of competition season. After the competition season, teams compete in one of more than 50 regional competitions. This year, the game required students to develop a robot that could move and stack large green recycling bins and gray rectangular totes for points. See Figure 1 for an illustration of a competition match from this year's game.

^aWhile a study attrition of this size may prove methodologically problematic, it is not uncommon in out-of-school settings for participant involvement to change over this amount of time as student schedules and commitments may frequently change. This issue will be addressed in more detail in the conclusion section of this paper.

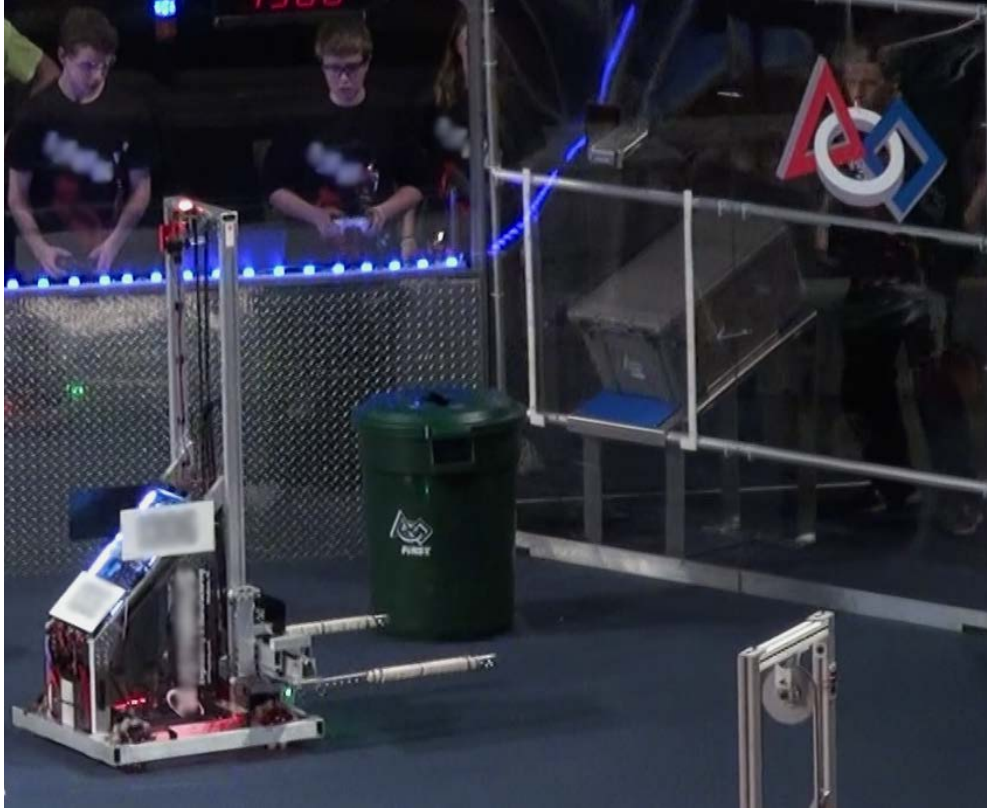


Figure 1. Acrobots robot and drivers at FRC regional competition match.

The Acrobots^b are an after school club hosted by a community group in a mid-sized Midwestern city, which has participated in the FRC competition for a number of years. They are repeat winners of the FIRST Chairman’s Award, considered the highest honor in the competition, which is awarded to the team that “best embodies the purpose and goals of FIRST”³⁶, and thus are an excellent example to study for insights into interest development. One of the hallmarks of the Acrobots team is their student driven approach. Mentors are strongly discouraged from playing any large role in team decisions, organization, pedagogy, or in designing and constructing the robot. This is not the model for all FRC teams, but is central to the governing principles (as decided by the student team members) of the Acrobots.

2.2 Data Sources

For the purpose of reporting in this paper, we will analyze changes in interest in engineering using quantitative data from pre- and post-interest survey responses from all 13 participants included in the study. While the quantitative data provide a useful overview of initial and evolving interest for the sample as a whole, the primary focus of this study is on qualitative data of three Acrobots students taken from team meeting observations (captured on video) and interview responses. These three cases were chosen to focus on two dimensions relevant to the situated study of interest development: the dynamics that occurs at the two highest phases of interest (emerging and well-developed individual interest); and, considerations of two different

^b Names of study participants and FRC team names have been changed to protect confidentiality.

levels of legitimate participation (newcomer versus old-timer). We observed that those with newcomer status also had emerging individual interest, and that old-timers had well-developed individual interest. Based on this, our three cases will represent: 1) an old-timer in the community (Walter) who has an existing well-developed interest in engineering that is maintained over time, 2) a newcomer in the community (Eli) whose level of participation in the community increases and whose initial emerging individual interest deepens over time, and 3) a newcomer (Lucas) who remains a peripheral participant in the community and whose initial emerging individual interest also deepens over time.

Of the three, Walter has the most experience on the team. This is his third year on the Acrobots team, and the second year that his role has been as the lead programmer for the robot. He is a Junior in high school, has a very strong knowledge of Java – the programming language used by the team – and has taken two AP science and some engineering courses at his high school. Walter also indicated a desire to major in computer science in college. Both Eli and Lucas are new to the Acrobots team and expressed interest in working with the programming team early in their participation. Eli is a sophomore, has a basic understanding of Java, is taking one engineering course in high school, but has not taken any AP science courses. Lucas is a freshman, has no previous experience working with Java, and has never taken either engineering or AP courses in high school. Both Eli and Lucas are undecided in their plans for a future college major. All three students previously participated in the FIRST Lego League program prior to joining Acrobots.

2.3 Data Collection

The general methodological approach employed in this study was a case study³⁷. Three methods of data collection were used as complementary aspects of the case study. The first was a quantitative survey based on the FPMID used to assess differences between initial (pre-) and final (post-) interest in engineering. The second was a semi-structured interview designed to provide complimentary information on each participant's experience prior to and during the FRC season. The third was a relatively large sample of observational video data collected in the afterschool program during the team's competition year. The videos focused on student action and interactions with peers, mentors and the tools used in the community of practice. In general, video data allows for a rich and accurate, although still incomplete, account of participant behavior³⁸, and in this study is used to assess the mechanism of interest development in engineering by way of the day-to-day behavior of students as they engage in the activity of this community of practice.

2.3.1 Interest Survey

To measure changes between pre- and post-competition season (the intervention) measures of interest in engineering we used the Four-Phase Interest Development in Engineering (FIDES 2.0) survey¹⁷. In previous testing¹⁷, the FIDES 2.0 was found to be reliable ($n = 145$, $\alpha = .89$) and to have both construct and content validity. The survey consists of 12 Likert-style items that asks students to rate their level of agreement with statements using a scale from 1 (*strongly disagree*) to 7 (*strongly agree*) based on six indicators of interest derived from the FPMID. See Table 1

for a full listing of FIDES 2.0 items. Scale scores were calculated by averaging the response values for all 12 items. In this way FIDES 2.0 scores match the 1 to 7 Likert-scale and are more easily interpretable. For example, a score close to 1 would indicate that the average responses to the positively phrased items were *strongly disagree*, thus indicating very low interest in engineering. Similarly, a score close to 7 indicates very high interest in engineering. As a matter of clarity, the FIDES 2.0 survey is designed as a unidimensional scale to determine a relative interest level, which is useful in comparison for between- and within-subjects studies. The FIDES 2.0 is not currently able to identify particular phases of interest for any individual, such as those identified in the FPMID, and is not intended to do so in this study.

Table 1

FIDES 2.0 Survey Items

I enjoy learning about engineering even when it is very difficult.
When I'm working on something in engineering that I think is interesting, I continue working even when it takes a lot of time.
I work on engineering projects outside of school at least once a week.
I always learn more about engineering on my own if I find it interesting.
Knowing about engineering is extremely valuable to me.
I think everyone should know a lot about engineering.
I think of my own engineering projects at least once a week.
I'm inspired to come up with my own engineering projects to work on when I see something in engineering that interests me.
I know way more about engineering than other kids I know.
I know a lot about the engineering topics that I find interesting.
Compared to other students at my school, I am way better at doing engineering work.
When engineering interests me, I am confident that I can learn about it extremely easily.

2.3.2 Interview Protocol

Yin³⁷ recommends that interviews conducted for a case study follow a *line of inquiry*, but are also conversational and fluid in manner. To adhere to this guideline, semi-structured interviews were conducted with each participant after the Acrobot team completed their regional FRC competition. An interview protocol consisting of 15 key questions for three lines of inquiry was developed in order to provide a level of uniformity for each interview. However, since the interview was allowed to proceed in a conversational manner, interview questions were not always done in the same sequence and additional questions may have been added for an individual in order to follow a participant's thought process, ask for clarity or depth, or to be

sensitive to individual responses. The same Interviewer conducted all interviews and kept the list of key questions available to consult during the interview. Interviews were relatively short in duration (range: 11.50 – 26.47 mins, $M = 15.68$ mins), and were audio recorded for accuracy. See Appendix A for a list of key questions in the interview protocol.

2.3.3 Video Data Collection

Video data was collected by the first author during Acrobots team meetings over a seven month period. The general protocol for determining where to focus the camera was to prioritize capturing activity directly related to the team. Therefore, activity and conversations deemed to be purely social or outside of the work of the team were avoided. The lead investigator drew on his extensive prior experience with FRC as mentor to aid in the process of capturing relevant activity. In general, the researcher's relation to the team was solely as an observer. However, there were times when the researcher would prompt students to explain their work or when students would initiate interaction with the researcher. In these cases, interactions were limited, with the goal being to remain as unobtrusive as possible.

After completing video data collection, each video was reviewed and transcribed verbatim. Select still frames were added into transcripts when a visual depiction of the scene would aid in understanding the activity. Still frames were also used to analyze the physical relation of each participant during activity.

3.0 Results

3.1 Quantitative analysis of interest development for Acrobots as a group.

A sample size of 13 participants, even with within-subject (pre/post) measures is severely underpowered for supporting strong quantitative claims related to interest measures. Even though these findings must be carefully qualified, they do provide some holistic descriptors of the team's initial and changing interest, which can help to frame the qualitative analysis. To estimate Acrobot program effectiveness in developing student interest in engineering, we compared the pre-FIDES scale scores to the post-FIDES collected 20 weeks later. Pre-FIDES ($Mean = 5.47$, $\sigma = 0.74$, $\alpha_{pre} = 0.81$) and post-FIDES scale scores ($Mean = 5.79$, $\sigma = 0.67$, $\alpha_{post} = 0.84$) were consistent with previous findings that the FIDES 2.0 is a highly reliable instrument. Baseline interest in our sample was skewed high, which is expected based on self-selection of participants in the program. Also, neither sample was normally distributed, which is also expected from this population, where there is considerable self-selection for participating in highly time-consuming STEM activities outside of school (See Figure 2 for distributions of the Pre- and Post-FIDES scale scores). The comparison of Pre- and Post-FIDES scores revealed a statistically significant gain in interest over the 20 weeks of participation ($t(12) = 2.30$, $p = 0.04$, $d = 0.45$; see Figure 3). While using non-normal distributions violates an assumption for conducting a t test, there is strong evidence that the t test is immune to the violation of this assumption³⁹.

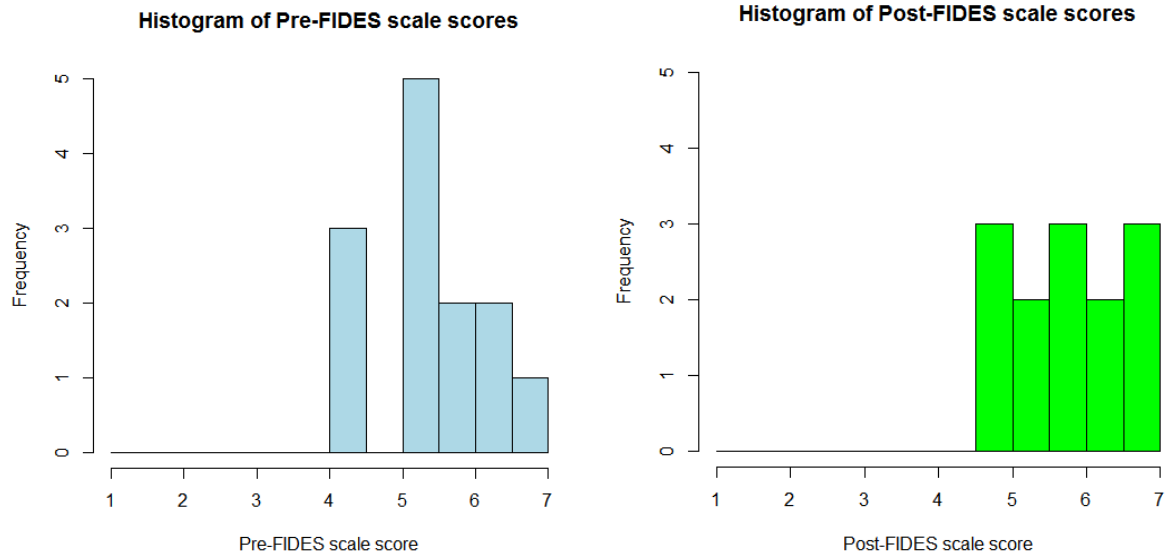


Figure 2. Histograms of Pre- and Post-FIDES scale scores

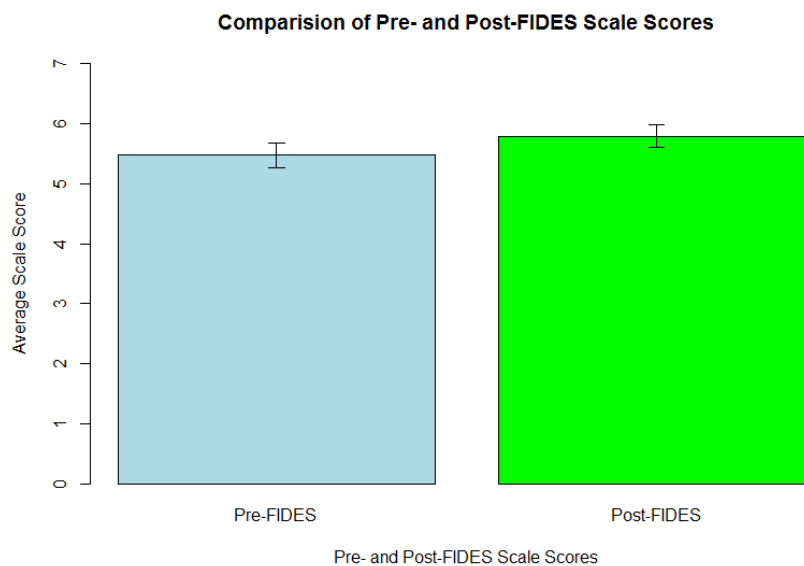


Figure 3. Comparison of Pre- and Post- FIDES scale scores, $p < 0.05$

3.2 Qualitative description of the mechanism of interest development

With a general quantitative pattern of interest growth evident in the student sample, we now turn to a qualitative account of interest development, utilizing video data and interview responses. The video transcript records as well as still images captured from the video will provide evidence to describe each of our three exemplar's participation in terms of the LPP framework. We will focus on *in situ* interactions within the community of practice, and identify instances of modeling, scaffolding, and coaching. The interview data will then serve as the basis for the majority of our analysis as evidence from the interviews suggests a trajectory through different phases of interest in engineering as well as some indicator of the level of participation for each

student. We will use this evidence to provide a description of each of our three student exemplars that includes their trajectories through phases of interest development (in terms of the FPMID) and participation within a community of practice (in terms of LPP) in robotics and software engineering.

3.3 Acrobots programmers as a community of practice

We begin our qualitative examination by focusing on the relationship between the three student exemplars in the community of practice, using the LPP framework to analyze their initial and final roles in the Acrobots community. While describing their interrelationships, we will also present evidence showing how old-timers enculturate newcomers into the community using modeling, coaching, and scaffolding – all traditional apprenticeship methods. The description will proceed chronologically in order to observe changes as they happen over time.

3.3.1 Pre-season

Our first observation of the Acrobots team happened 10 weeks before the beginning of the FRC competition season. Walter and Eli are in attendance at the beginning of the meeting and Lucas arrives later. Lucas spends his time working on a side project with a small group building a 3D printer, and does not work with the programming group. Meanwhile, Walter works with Eli to show him Java code for a programming competition that Walter is entering (see Figure 4). At this early stage we can see Walter in the role of old-timer and Eli as newcomer. As Walter explains an example of code (*NB.* Comments to the reader are in double parentheses):

WALTER: *((talking to ELI, pointing to Java code on computer screen))* And you can, like you can, what I originally did is I made it so I have a child class and I had different sub classes of that. When you extend it, you can make like different versions. You know you can make a scout, you can make a fighter, you can make a defender or whatever.

ELI: And I was thinking, I don't think it would necessarily need to be kept static between each specific. Like I don't think it's necessary if each, for if one was a scout. I don't think it's necessary for it to stay a scout. You just, switch to any other codings of that.

FV: Yeah, that makes sense. The main mechanism that will... Well, there are two things, two algorithms that I think will be most important. One of them is figuring out how. If you want to go to a certain location, how to get there. And so what I would recommend taking a look at, and it came recommended to me is "a-star". The "a-star search algorithm".

In this segment, Walter uses the vocabulary (“class”, “extend”, “algorithm”, “a-star”) native to the community of practice and Eli begins to explore how the existing work could be modified but lacks the specific vocabulary or knowledge to do so. This interaction, where Eli is looking at a complete product as Walter assists him in understanding the components, can be seen as an example of modeling the work of a programmer in this community²⁷. Modeling, particularly

using completed work as an example, is a way of early enculturation of a newcomer, and is a key component of legitimate peripheral participation.



Figure 4. Eli (left) and Walter (right) reading through Walter's Java code.

At the next meeting (one week later) that we observed the Acrobot, Lucas walks directly over to Walter immediately after the team meeting and says "I want to learn how to program!" Walter smiles and they talk a little about the programming competition that the team has entered, but Lucas doesn't actually work with the programmers until the next week. At this third meeting Walter sits at the center of a group of newcomers to the programmer's community, including Eli and Lucas, and begins to describe the basics of how their robot code will be organized this year (See Figure 5). At one point Walter establishes each person's familiarity with Java. From the transcript we see Walter point to Eli and say, "Okay you're familiar with [Java]... ((looks to another student)) You're also. Okay, ((looks at Lucas)) and you're... I can talk you through Java later." Walter seems to be organizing the level of instruction each will need as they proceed. Evidence for this can be seen from the way that Walter then organizes activity for each newcomer. He helps Eli find the code for the visual display, called a smart dashboard, that is available to the robot operators during competition, and allows Eli and another student to read through that code and interpret what it does. This is another form of enculturation employed by Walter, which can be seen as an early form of scaffolding, because Eli depends on peer support to make sense of a worked example of code, but is not expected to write any code himself. This appears to be a higher level of legitimate interaction with the practices of the community, but is still very much near the periphery of activity.

While Eli engages with a scaffolded activity, Walter explains some of the robot code, line by line, to Lucas. This is the same method of modeling that Walter used with Eli two weeks earlier, which lends support to the claim that modeling existing programming code is the first stage used by Walter, of enculturation for a newcomer, especially for those with no basic knowledge of Java. At this point, Eli appears to now have moved a small but noticeable increment towards full participation. In contrast, Lucas remains where he began, at the very edge of the periphery.



Figure 5. Eli (seated left), Lucas (seated right) and Walter (standing) work on robot code.

On one of the final days of the pre-competition season, we can see Walter work directly with two brand new students to the programming group, walking them through the basic code used on last year's robot. Again this is the same method of modeling that Walter used with Eli and Lucas as they first joined the team. While Walter works with the two new students, both Eli and Lucas demonstrate that they have progressed in their enculturation – and thus their participation – with Lucas continuing to stay closer to the periphery of activity than Eli. Eli and Lucas work side by side at the programmers' table (See Figure 6), but their activity is different.

Lucas is seen working through a basic example of robot drive code that is available online. He has two windows open on his computer, side by side, one with the example code and one with Java code titled "ASimpleJavaBot.java". Here we see him attempting to copy the example, and he encounters a vocabulary word commonly used in robotics programming, "teleop". He asks a team mentor: "What is a teleop?" but quickly answers the question himself saying "Oh, that's when you're driving operator controlled." The mentor confirms this, and Lucas then says, "I just have to copy all of this [example code]? This is great." This is an example of him beginning to understand the use of this word, and becoming further enculturated. Lucas is using the example code as scaffolding for his learning. He is writing code, but does not have to know *how* to write it. However, it is supporting his understanding of the design and vocabulary used in the process.

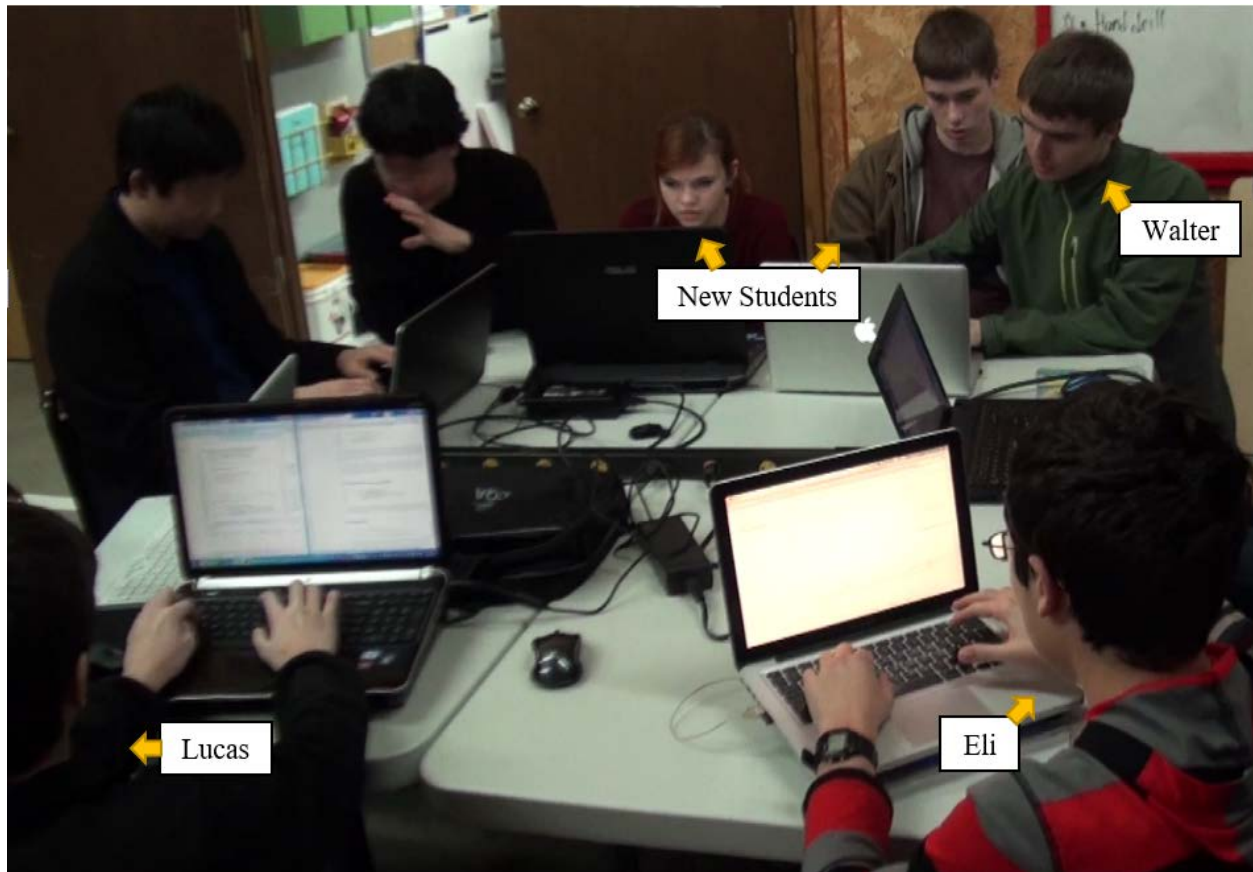


Figure 6. Lucas (left front), Eli (right front), Walter (right back) and two new students (back, center) work on programming.

At the same time, Eli is seen writing code on his own for a program titled “Collatz Conjecture”. This code does not directly relate to the robot (it is actually a common task for learning programming), but it is code that he must develop himself. This represents a higher level of participation in the type of work done by the community, but it is still not at the center since it is not for the competition robot.

During the preseason we have strong evidence to support the claim that modeling and scaffolding are both used by old-timers to enculturate newcomers into the practice of the community. As newcomers increase in competency, they are tasked with activities that progressively increase in relatedness to the authentic work done by old-timers in the community. This trends continues during the competition season.

3.3.2 Competition season

We now examine the activity of Eli, Lucas and Walter during the competition season. The new game has been revealed and Walter spends much of his time writing code for the robot that will compete in this year’s regional competition. At this stage, many of the newcomers who joined the programming group late in the preseason no longer work with the programmers, and have moved on to assist in the mechanical group. This may be because the old-timers have less time

during the competition season, to support this very low level of competency in Java and writing code for the robot. Without any support, those on the very edges of participation may not be able to engage in the practices in any way. However, this inference is very speculative, and we address the need for further evaluation in the conclusions of this paper. Walter does organize the others remaining in the group to support the work of writing programming code for the competition robot. There is one other old-timer who assists in writing code for the competition robot, and several other newcomers whose support for the group comes through the completion of simpler tasks or through observation (similar to the organization of work of Lave's novice tailors). Eli and Lucas are both engaged in these simpler tasks as they become closer to the center of participation.

Eli has spent much of his time during the competition season *commenting* on robot code written by Walter. Code commenting is considered an essential practice for professional programmers. By Walter asking Eli to comment his code, he further enculturates Eli into the community of practice. This activity is also at a very high level of complexity for Eli, since it is both an example of Walter modeling robot code and a scaffolded activity for Eli, as he must interpret (but not generate himself) the function of each line of code by himself.



Figure 7. Eli working alone to write comments for code previously written by Walter.

Meanwhile, Lucas, who appears to still be less fluent in Java than Eli, spends much of his time observing Walter as he works (See Figure 8). Walter is modeling the practice of the old-timers in the community by allowing Lucas to watch him work. Lucas knows enough about the practice to understand much of what Walter does, and he interjects with questions when he doesn't. This illustrates Lucas' continued legitimate peripheral participation in the practices of the community, which is further from the center of activity than Eli.



Figure 8. Lucas (right) observes Walter (left) writing robot code.

On the final day of competition season, Eli seems to have continued to move closer to full participation, while Lucas remains near the periphery. An excellent illustration of this occurs while the Acroboters are running final tests on their competition robot. A table is set up for the *drive team* who will operate the robot. At this table are the three drivers (all from the mechanical group), the two old-timers from programming (including Walter) as well as Eli. (See Figure 9) As the team sets up testing the robot, Eli suggests a piece of programming that he could write for the robot. Walter considers this but suggests an alternative project:

WALTER: Well actually, I'm not sure, that might be a little more complicated, but one thing you can do that would still be interesting... So you know the 'drive-to-tote'.

ELI: Yeah.

WALTER: So... Right now the autonomous program has 'align-with-targets' and 'drive-to-tote'.

ELI: Yes.

WALTER: So, what you could do, is *just* use 'drive to tote', cause right now our plan is to use both of them at the same time so it'll be aligning as it drives forward. But what you could do is have, make an autonomous program where it just drives to the tote, grabs it, lifts it up, drives backwards.

Here Walter is giving Eli a task that asks him to write code for the actual competition robot, which is the center of activity for the community. While this may at first seem like Eli's first full participation, it is not quite at that level. It is in fact a scaffolded activity. The scaffolds exist in that Eli is asked to revise the existing code, 'drive-to-tote', to write a more basic version of the autonomous code that already exists. Walter explains that the code that Eli is asked to write is a backup in case they have problems with the existing code.

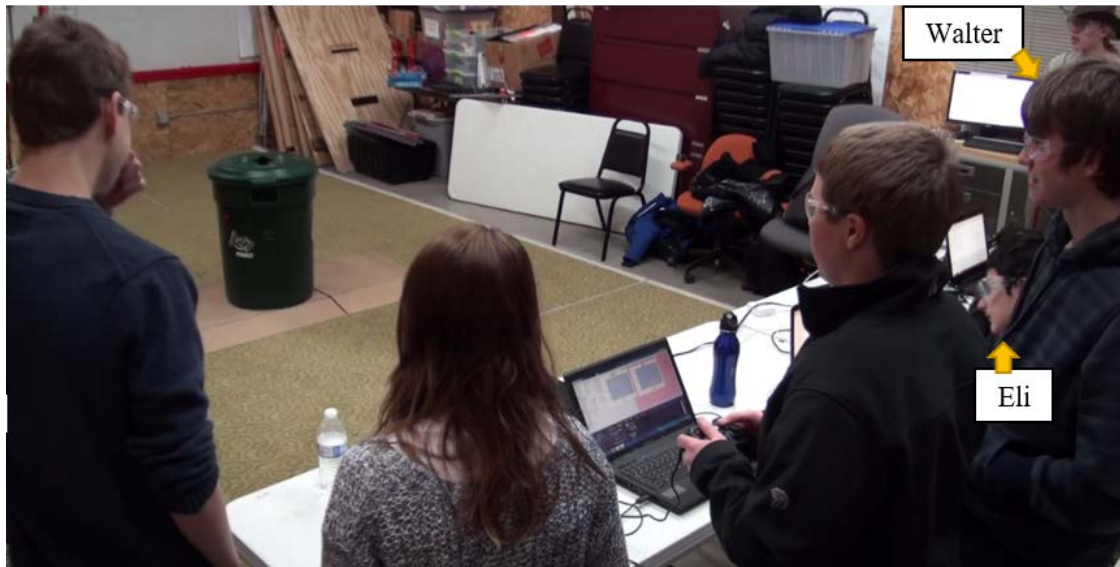


Figure 9. Robot drivers (three leftmost individuals), and Walter (standing far right) testing the robot, while Eli (seated) works independently.

While testing the robot, there is some malfunction where the robot begins to shake violently when the operator attempts to rotate the robot. Walter quickly identifies this as an issue with error correction (called PID) used for this function and works by himself on the main robot code to fix the problem. While Walter works, we see Lucas standing far behind the table that the robot testing is happening at. Here he is still observing Walter work, but from a further distance than usual. At this point we can interpret the level of participation for our three exemplars as follows: Walter is engaged by himself at the center of (or full) participation; Eli is very near full participation as he is engaged in a scaffolded task, with intermittent support from Walter, very close to the center of activity; and Lucas is still near the periphery of participation as he stands back and observes the activity of others. Figure 10 is an excellent illustration of these differing levels of participation.



Figure 10. Activity of Walter (seated, top left), Eli (seated, bottom left) and Lucas (standing, far right) during the final testing of the competition robot.

3.3.3 FRC regional competition

At the regional competition, the divide between those at the center of participation and those further away becomes amplified. This is most likely due, in part, to the structure of the competition. Each team is given a 10 foot by 10 foot “pit” where they are able to set up a small workspace to work on their robot during the competition (See Figure 11). Since this space is small, the number of students who can be in the pit at any one time is limited, so only those closest to the center of the community of practice participate in the work to be done to maintain, improve, and repair the robot. Six members of the team occupy this space for the majority of the competition. One is from the chairman’s award group, four are from the mechanical group, and Walter is the lone representative from the programming group. Walter can be seen as very much at the center of activity of the community and is fully participating in this activity.

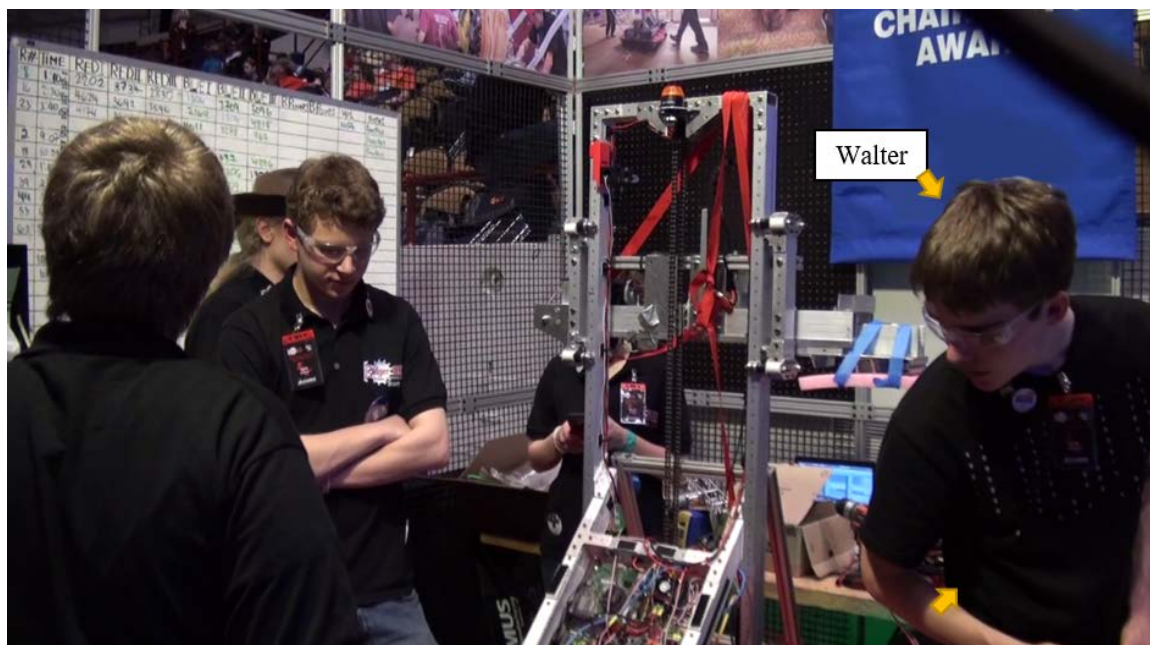


Figure 11. Walter (right) and other Acrobots team members work on the robot in the team pit.

During the competition, Eli and Lucas work with the other old-timer programming group member on processing scouting reports that the Acrobots make for each team in each match of the competition. To briefly explain the process, during every match at the regional competition, the Acrobots will scout other teams. They do this by assigning an Acrobots team member to watch a specific team in each match and fill in a scouting sheet form detailing the actions of that team. Each of these scouting sheets is then delivered to a group that will scan in the scouting sheet form. Data is collected from each scouting sheet and added to a file, and this data will be later analyzed to rank the quality of each other team at the competition.

For the majority of the competition, Eli is charged with collecting and delivering the scouting report forms to the scanners. Lucas’ is one of these scanners, and his role at the competition is to scan each of the documents once they are received and to manage the file folder that these documents are stored in (See Figure 12). This shows that at the regional competition, Eli and

Lucas both participate near the periphery of the community. While this is consistent with Lucas' status within the community, it appears to be a bit of a step back for Eli.



Figure 12. Eli (right) delivers scouting sheets (pictured on left), while Lucas (center) and another Acrobots student scan them.

3.3.4 Video data summary

To summarize our results from examination of the video data we provide a graph representing the levels of participation for each of our three exemplars over time (See Figure 13). The y-axis of the graph, level of participation, includes increments from periphery, near periphery, partial participation, near full participation and full participation. The x-axis of the graph, Acrobots season milestones, is separated by increments over the time of the Acrobots year and includes: start of preseason, end of preseason, start of competition season, end of competition season, and regional competition. These times are taken as approximations, and the level of participation is estimated based on observed behavior.

From Figure 13 we can see that Walter (top connected points), already a full participant and an old-timer in the community maintains his full participation at the center of activity throughout the duration of the competition. Eli joins the programming group as a newcomer, moves closer to full participation throughout the preseason and competition season, and takes a step back towards peripheral participation at the regional. Lucas also joins the programming group as a newcomer, and moves closer to full participation, but remains near the periphery, maintaining this level through the regional competition.

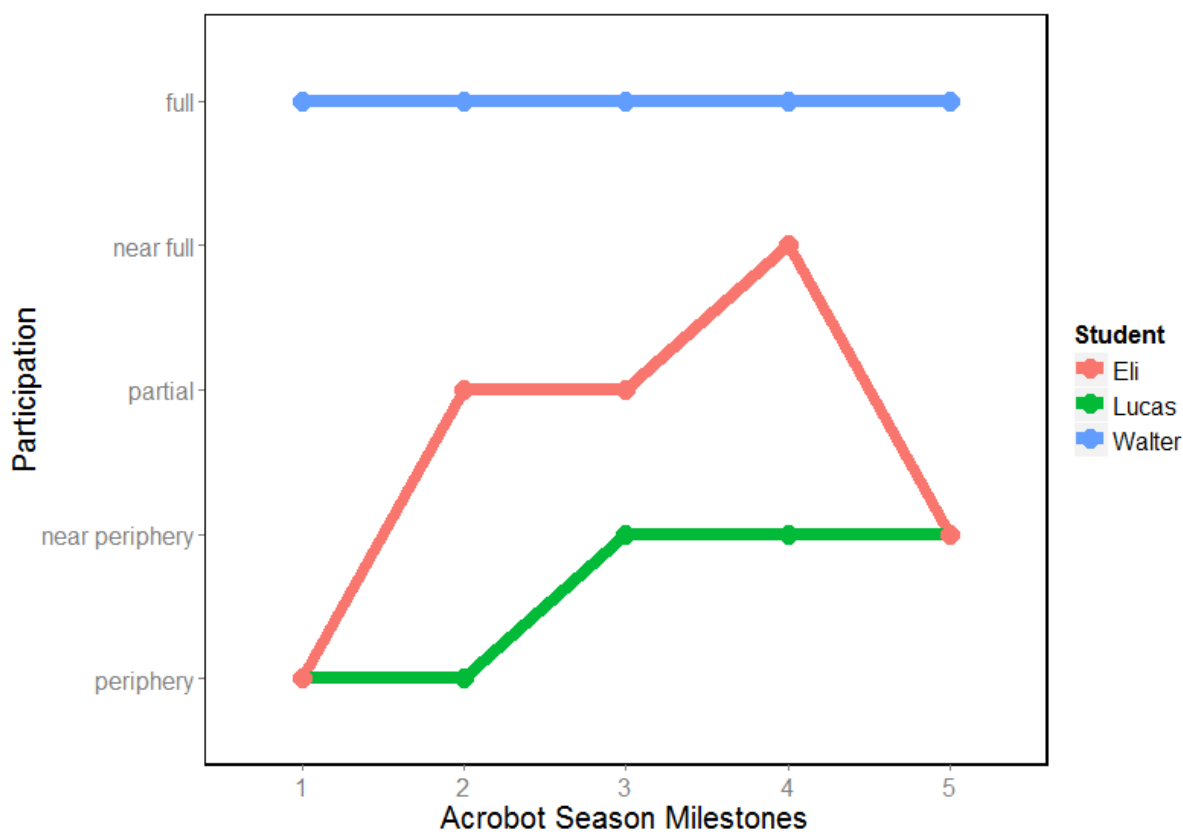


Figure 13. LPP of each exemplar student over time. Milestone 1 is the beginning of the preseason, Milestone 2 is the end of the preseason, Milestone 3 is the beginning of the competition season, Milestone 4 is the end of the competition season, and Milestone 5 is the regional competition.

3.4 Trajectories along FPMID and LPP models

In this section we will use evidence from our interview with each of our exemplar students to describe how they have changed in terms of the four phases of the FPMID over the course of their lives and in terms of the LPP over the course of their participation with the Acrobots. Each student will be examined individually, followed by a summary across all three.

3.4.1 Walter – Well-developed individual interest and a community old-timer

Well-developed individual interest. We begin our examination of our exemplars by introducing evidence from our interview with Walter to establish his trajectory along the four phases of the FPMID. To describe his early experiences with engineering, Walter told us that he had “always been kind of interested in science and math.” Walter’s father was an engineer, and heavily influenced Walter’s activities towards engineering. He encouraged Walter to join both FIRST Lego League and later FRC, and generally included Walter in his own passion for engineering and tinkering, including working on building and design projects and providing Walter with a Lego Mindstorms robot. Walter sums this up by saying: “I mean, a lot of the toys that I had are a

result of [my dad's] like of engineering. So, you know we have always been building stuff like doing wood working projects and stuff." Walter describes his view of engineering at this stage in his life as "kind of a fun thing to do," and that he enjoyed working with his dad on these projects, but added, "Not in the sense that I wanted to grow up and be an engineer." Walter appears to have experienced triggered and maintained situational interest early in elementary and into middle school as evidenced by his description of positive feelings, and his enjoyment of engineering type activities initiated by his dad. His joining FIRST Lego League in middle school also demonstrates a beginning to seek reengagement with engineering activities on his own, and here emerging individual interest likely began to develop. Walter's interest was able to quickly develop as he then joined the Acrobots his freshman year.

His involvement with the Acrobots demonstrates his quickly deepening individual interest in engineering, and more specifically in software engineering. According to the FPMID, increases in engagement, stored knowledge and value are all evidence of increasing individual interest. First, this year Walter spent a very large amount of time (5 days a week during the competition season) at Acrobots, and he explained that after a while he also began to work on programming projects at home as well. This shows that his level of engagement quickly increased at this point. Second, he explains that his knowledge of programming strongly increased during this time. At first he said: "My freshman year, when I joined the team, I didn't really know what I was doing." However, by his second year he was able to "do pretty [much] all the programming by [him]self at [his] house." His value for the domain also increased, as by the end of his second year he planned to be a software engineer and was able to apply his programming knowledge in his day-to-day life.

At the beginning of the year that we observed the Acrobots, the evidence suggested that Walter was in a well-developed phase of individual interest. He was deeply engaged, and had significant stored knowledge and value. This competition season Walter seemed to change the focus of what type of knowledge and skill he wanted to work on as a software engineer. In his interview, Walter describes how his increased interest in engineering this year was due to his work on managing software engineering projects, and that, to him, this skill was very valuable in the real world. While he was already in a well-developed phase, we can see that increasing his knowledge and seeing value for that knowledge deepened his interest.

INTERVIEWER: So how did, umm, how did your work this year impact your interest in engineering you think?

WALTER: Umm...well...I mean, I'd always... Well I, you know, last year, I did a lot of the pro-, I did, you know, pretty [much] all the programming by myself at my house. And this year, I guess I...it was more of a...a little bit more of a management role. And I kind of like that, because, like, and I, that's something that's important in the real world for, and real, you know, software engineers, it's being able to work together. So, I guess it improved my confidence there, 'cause like I can actually...it...lets me know that I actually, you know, could work together at doing big software, and it's fun for me, so.

INTERVIEWER: Yeah. Okay, and so that was a positive influence then on, on maybe your overall interest in being an engineer?

WALTER: Mhmm, right.

Walter appears to have used his participation in FRC as a means to develop knowledge that had value to him, thus deepening his already well-developed individual interest in engineering. This claim is further supported by evidence from Walter's FIDES scores, where he went from a Pre-FIDES score of 5.33 to a Post-FIDES score of 5.58.

Legitimate peripheral participation to full participation (newcomer to old-timer). There is strong evidence from interview data that Walter began with the Acrobots as a clear newcomer to the community of practice and quickly grew to become an old-timer. He describes his early participation as very limited, and that he didn't even work with programmers his first year.

[At first], I kind of just joined the mechanical team 'cause I had been...like on the [FIRST] Lego League team I had been, you know, more interested in building with Legos than programming. And, I wasn't very good at mechanical. And I kinda wanted to like check out programming, but...umm [two students at the time] were doing that and so they kind of...umm...they kind of were like, "Oh, you know, two people's enough. So I...I don't know. I was a little bit...I mean that's, that's understandable because it was like it wasn't really until build season that I err, 'til like right before build season. It would've been a lot to learn, and they didn't want to spend time training me.

This involvement seems to match what Lave and Wegner would call legitimate peripheral participation. He worked with the team on the actual FRC competition robot, but in a very limited way, and since he did not have enough knowledge and skills yet, he was not given many responsibilities in the tasks carried out by the community. This would have allowed him to see the competition as a whole, before participating more fully, and perhaps given him some idea of the programming skills that would be necessary to do more direct work with the robot.

In his second year he was able to more fully participate. After his first year, he learned a lot of Java programming outside of Acrobots, and was able to put that to use by writing the majority of the code for the robot. This is a very abrupt change in roles within the team, and he appears to have quickly become an old-timer in the community as he developed a deeper knowledge of programming, and software engineering and was given much larger responsibilities.

Based on our assessment of video data we believe that throughout this year with Acrobots, Walter can be described as an old-timer with full participation in the Acrobots community of practice. Evidence from our interview with Walter offers further support for this claim. Walter's current role with the Acrobots, is still as the lead programmer. However, this year, in line with his goals to develop project management skills, he is much more deliberately facilitating the entry of newcomers into the community. He said: "I...kind of wanted like the new people to, you know, be able to, you know, jump in and do stuff, and feel like they're contributing." To do this he began to employ methods of classic apprenticeships: modeling,

coaching, and scaffolding – although he most likely would not identify them as such. This was not done as a deliberate teaching strategy, but seemed to organically evolve out of his desire to bring newcomers closer to full participation. For example, without explicitly saying so, Walter utilized scaffolding for other's to participate in writing this year's robot code. He said: "[I] wrote the basic, the structure. I figured out how like everyone was going to fit together. And then I gave people, I tried to figure out modules that other people could work on." As an old-timer, he took on the responsibility of assessing the quality of work done by the newcomers. He said: "Someone, like, each person worked on kind of a different thing. And I think that worked pretty well. I mean, I still...I still like, you know, checked all their coding." His goal was to develop their abilities enough, "So that they can contribute a little more next year." This behavior may have been driven by his desire to improve his skills as a software engineer, but he also felt a great "responsibility to teammates," another key characteristic of an old-timer. Based on evidence from Walter's description of his work with the Acrobots he seems to fit the role of old-timer very well in the LPP model of participation in a community of practice.

3.4.2 Eli – Emerging individual interest and a community newcomer

Emerging individual interest. We now turn to evidence from our interview with Eli to examine his trajectory along the phases of the FPMID. Eli's early experience is very similar to Walter's. He reports liking math and science at a very young age, because "I've always been better at math and science than other things." This enjoyment later on helped him to catch hold of the idea that engineering might be a good career for someone with his interests. He explains this by saying, "I think that I had said I wanted to be an engineer before because there was a career day expo and someone came in and said 'if you like science and math, you might want to be an engineer' and I said to myself 'I like science and math, so I might want to be an engineer.'" This led to Eli attending a summer camp aimed at elementary students, hosted by the Acrobots team, to learn about engineering. He described this experience as, "sort of like [FIRST] Lego League but it was a summer camp, and you would go there and you would get a partner and you would build to do a challenge. You would learn how to program, you would do the challenge and there would be a little bit of a competition." Later, during middle school, Eli did join a FIRST Lego League team for two years, because, "It was fun, and it was solving problems." In particular, he enjoyed this because the challenge lasted for weeks rather than just hours at a time, like in school. Eli also has family members who have supported his interest in engineering activities. Both of his parents work in the IT field, but Eli did little elaboration about how exactly they influenced him other than that they were "very encouraging" of his participation in out-of-school activities that had to do with engineering. Eli, like Walter, appears to also have had very early triggered and maintained situational interest in elementary school and into middle school. He had strong positive feelings and in middle school began to seek reengagement with engineering activities. His thoughts about engineering as a possible career may indicate an emerging individual interest in middle school. As Eli entered high school with an emerging individual interest, he sought out further engagement in engineering by joining the Acrobots.

The year that this study was conducted Eli was a sophomore in high school and began his first year on the Acrobots. Having taken an engineering class in school and knowing some basics of

Java programming indicates that Eli began the season with some knowledge of programming and engineering. This may explain why he became so quickly enculturated into the Acrobots programming group's community of practice. He also indicated that he had a fairly high value for this domain when he said, "I feel like in the future I can use these skills to help people." and by indicating that he continued to want have a career in engineering. His misconception of what a career as an engineer might be like was revealed when he compared it to the IT work that his parents did. He said, "IT from what I have seen requires, I'm not going to say that engineering doesn't require people skills but, IT requires a lot more I think." We refer back to our video recorded observations of Eli as evidence of his increased knowledge in the domain, which could be an indicator of his emerging individual interest deepening. He also told us that during the competition season he was attending Acrobots meetings five times a week, which shows a great level of engagement in the domain. Eli did tell us during the interview that being a part of Acrobots has increased his interest in engineering. Based on this we believe Eli to have begun the Acrobots year with emerging individual interest that has deepened, but is not quite at a well-developed phase. Further support for our claim that Eli's interest has increased during the year comes from his FIDES scores, where he went from a Pre-FIDES score of 4.42 to a Post-FIDES score of 5.67.

Legitimate peripheral participation transition to near full participation (newcomer). Evidence from video observations suggest that Eli began the Acrobots season as a newcomer to the community of practice, and engaged in legitimate peripheral participation. Our observations further suggest that he moved quickly away from the periphery and eventually was given tasks that, with support, exhibited near full participation in the community. When these supports were removed during the regional competition, he returned to a near-peripheral level of participation. Our interview with Eli further supports this claim. The interviewer asked Eli about his role with the team this year, and his somewhat vague response may show that he did not have a role as a full participant. Eli told us the following:

INTERVIEWER: Okay and what kind of things do you do with the programming?

ELI: Programming.

INTERVIEWER: Okay umm...

ELI: I could be more specific with some time. Let's see. Well...

INTERVIEWER: What's something that you, did you program things specifically for the robot?

ELI: Yeeeeee ((seems unclear, confused))

INTERVIEWER: Or did you work more, I know [another student] did work a lot on developing the survey or the umm... the scouting system. Did you work with him on that?

ELI: A little bit.

INTERVIEWER: Okay.

ELI: I worked more with the robot.

As a newcomer, it may be that a student has difficulty understanding their role within a community of practice without being explicitly told what it is. Eli's confusion during the interview supports our claim that he had not moved to full participation by the end of the year. His experience may lay the foundation for full participation in the future and becoming an old-timer in the Acrobots community.

3.4.3 Lucas – Emerging individual interest and a community newcomer

Emerging individual interest. Finally, we examine evidence from Lucas' interview to map his trajectory across phases of the FPMID. Here again we see the early influence of Lego robotics and tinkering on the student's interest in engineering. When asked when he was first aware of having an interest in engineering, Lucas said, "That sort of started before I joined an FLL [FIRST Lego League] team, I used to live in [another city], and I bought a [Lego Mindstorms] NXT kit. I tinkered with that for a while and then when I moved [here] I learned about the FLL [FIRST Lego League] teams and then I joined a team in my first year." He explained that he enjoyed working with the FIRST Lego League team in middle school, "because it was fun." While his dad was responsible for introducing Lucas to Lego robotics and encouraged him to join the FIRST Lego League team, Lucas does not describe anyone in his immediate family as being involved in engineering or technology work. He does, however, explain that they are supportive. He says, "Yeah, they encourage me. They drive me here." Based on Lucas' interview, we believe that he, like our other two exemplars, experienced triggered and maintain situational interest very early on in life and into middle school, and this is when it appears that Lucas began to enter the emerging individual phase of interest.

Now in high school, Lucas is a freshman and this is his first year with the Acrobots. He joined the team in order to continue to pursue his interest in engineering. One area that may have restricted Lucas' interest development early in this season is his lack of knowledge of some of the tools used in the Acrobots community of practice. Lucas did enter with some knowledge of html and JavaScript, but these only had limited utility within this community. However, based on his interview it seems Lucas had a very high value for learning engineering, and this value drives his desire to learn more. When asked if he liked doing engineering type work, Lucas said, "I think it's extremely important and valuable to know a lot about engineering. I've used engineering quite a bit." and later added, "Well, when I grow up I definitely want to do something with engineering and computers and something that will definitely relate to this. So, I think its valuable cause when I get my job eventually, then I'll already know some skills from what I've done here." This passage strongly supports our claim that he wants to learn engineering because he values that knowledge. Lucas appears to have some domain knowledge and a strong value for engineering.

Where Lucas differs from Eli and Walter is in his level of engagement. He indicated that he spent two days a week participating at Acrobots during the competition season. This level of

engagement is not trivial, but lags behind the very high level of the other two exemplars. However, there is strong evidence that a future increase in engagement may ensue. We believe Lucas' response to the question, "Has your interest grown since you've been on the FRC team?" provides support for this claim. He responded by saying,

Oh, yeah. Definitely grown cause like at the beginning, before I joined, I wasn't doing that many projects or anything, but now I'm planning on starting a project with my dad and maybe my brother to build like a raspberry pi and some stuff.

This statement is also evidence that Lucas' interest in engineering has increased during the year. He was able to increase knowledge throughout the course of the year, but based on his level of participation this learning was somewhat minimal. We therefore believe Lucas deepened his emerging individual interest, but is not quite at a well-developed phase.

Legitimate peripheral participation to near peripheral participation (newcomer). Evidence from our video data suggest that while Eli appeared to move closer to full participation in the community, Lucas' participation only increased by a small amount. Our interview supplied a limited amount of support to this claim, as Lucas did not talk much about his role on the team. He did indicate that he was a "programmer," but does not elaborate. His response to a question about why he continued to work with the Acrobots does give some indication of his idea about his role with the team. He told the interviewer:

Well, I like being here cause you can kind of personalize what you want to do. It's a student led team. You can choose if you want to work on this. You can choose if you want to work on that. You can do different things every day. You're not always doing the same thing. Like, over the summer, I started a project to build a 3D printer, cause we found a 3D printer kit. So, we're almost done with the 3D printer. We had to put it on hold a little bit for build season.

With the 3D printer project, Lucas worked as an equal with another student and was able to fully participate in this activity. Perhaps, this focus on the work that Lucas did as a side project is due to his lack of a specific role within the programming community. Based primarily on our observations of Lucas' activity throughout the course of the season, we believe that he began the year as a newcomer and had legitimate peripheral participation. His level of participation appeared to only increase a very small amount by the end of the year.

3.4.4 Summary of interview data.

Throughout their lives, Walter, Lucas, and Eli demonstrated very similar trajectories along the four phases of the FPMID. They all had early interest in math and science, began to express this through playing and learning from Legos and Lego Mindstorms robots, and described this interest based on these activities being fun. In middle school they all participated in FIRST Lego League competitions and sometime in middle school began to consider the idea of engineering as a potential career path. Each of the three sought out participating with Acrobots in high school in order to further pursue their emerging individual interest in engineering. They all began to value this knowledge, and while all three had limited knowledge of programming (with Eli having the strongest initial background of the three) they each sought to learn more. All of this provides evidence to suggest that each student experienced triggered and maintained situational interest in elementary and middle school and during the transition from middle to high school an

emerging individual interest in engineering began to develop. We also found strong evidence suggesting that each student's interest was developed during the course of the Acrobots season.

As they began working with the Acrobots as newcomers, these three students all experienced legitimate peripheral participation with the programming group. Both Lucas and Walter were not able to move much closer to full participation within this community during their first year, because of their lack of prior domain knowledge for programming and robotics. In contrast, in his first year Eli had more, but still limited success, in moving closer to the center of the Acrobots community. Since Eli and Lucas are in their first year with the team, it should not be surprising to find that they finished and ended the year as newcomers, and their level of participation reflects this. This year's experience might entice them to return next year ready to move closer to the center of the community and its practices. Walter seems to have already established himself as an old-timer in the community, and plans to return next year to continue to build the community and improve his practice.

3.5 Results summary

To summarize our results, we find it useful to graphically represent the relationship between an individual's phase of interest and their level of participation at the end of the competition season (See Figure 14). In Figure 14 we include our three exemplars, as well as two other students on the team to add some perspective. We see that Walter ends the competition season at a well-developed phase of interest (phase 4) and as a full participant in the community of practice. Eli ends the competition season with a deepening, but still emerging individual interest (phase 3) and is near being a full participant in the community of practice. Lucas also has a deepening but still emerging individual interest (phase 3), but in contrast to Eli, is only near the periphery of participation in the community.

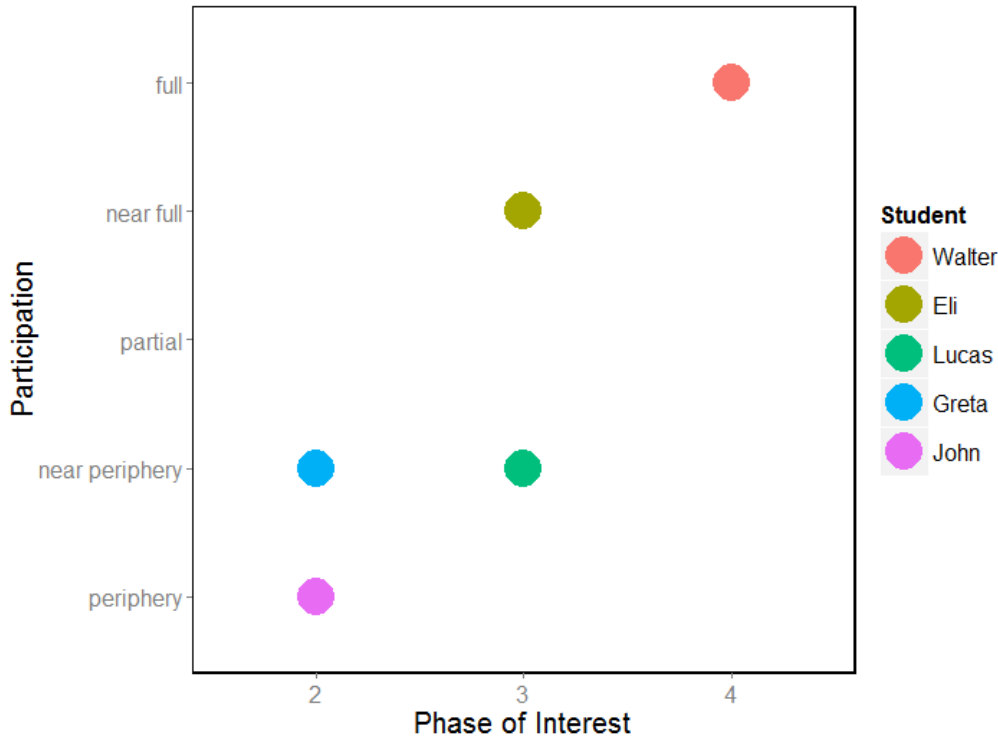


Figure 14. Phase of interest and level of participation for Acrobots individuals at the end of the competition season. For the phases of interest on the x-axis, Phase 2 is maintained situational interest, Phase 3 is emerging individual interest, and Phase 4 is well-developed individual interest. Note: No participants were observed in Phase 1 of the FPMID.

4.0 Conclusion

In this paper we sought to answer the overarching research question: How is student interest in engineering maintained and developed while participating in an out-of-school robotics competition? To do so, we pursued three goals: 1) (theoretical) add to and support existing literature in interest development and socio-cultural learning; 2) (empirical) further the evidence based connections between interest development and social cultural learning theories; 3) (practical) contribute guidelines and recommendations to program managers and developers on designing out-of-school learning environments that promote interest in engineering.

To address our first goal, we demonstrated how socio-cultural learning theories mutually contribute to understanding the mechanism of interest development. Support for this claim comes from interviews with three of the Acrobots members, which revealed that they all progressed along Hidi & Renninger's Four Phase Model of Interest Development in somewhat similar fashion, and interview and observational data show how these same students fit into the communities of practice model proposed by Lave & Wenger. We demonstrate this relationship in Figure 14. To address our second goal, we provided empirical evidence that individual interest phase changes emerge through a process of enculturation that is supported by modeling and scaffolding, as predicted by socio-cultural learning theory. Support for this claim was done by first establishing that the Acrobots experience, as an out-of-school engineering club, was successful in developing interest in engineering among the students that we surveyed ($n = 13$),

based on a statistically significant increase from pre- to post- interest survey results. Our second, and primary, level of support for this claim is based on results from our observations of team activities that show that the Acrobots' group practices closely align with Lave & Wenger's⁶ model of legitimate peripheral participation in communities of practice. We now address our third goal of generating practical recommendations.

In this final section, we begin by detailing the benefits obtained from drawing on both the FPMID and LPP models to describe the connection between individual interest development and social cultural learning. Based on this connection we then describe the practical contributions of our findings, followed by limitations of the study, and future work that would aid in furthering our understanding of engineering interest development.

The Four-Phase Model of Interest Development⁵ describes interest development as being composed of varying levels of positive feelings, stored knowledge and stored value for a domain. In the FPMID, positive feelings play a larger role in early phases of interest development (triggered and maintained situational interest), while knowledge and value are more central to higher phases of interest development (emerging and well-developed individual interest). To further validate this theoretical model we found evidence that in this out-of-school engineering program, the students we examined described strong positive feelings during early interest development, and increasing knowledge and value for engineering as their interest began to deepen. We also find evidence that both knowledge and value increased in parallel for the students in our study, which supports inclusion of both value and knowledge in the FPMID model.

Our observations of the Acrobots also provide further evidence that progressing from legitimate peripheral participation to full participation in a community of practice is an accurate depiction of how learning and enculturation occur in authentic learning environments. In the group we studied, the newcomers were lacking in the knowledge and skills needed to fully participate in the Acrobots programming group. The old-timers supported the newcomers using classic apprenticeship methods, including scaffolding and modeling. As the newcomers gained knowledge and skill, different supports were used to help them move more closely to full participation. We believe we provide very strong support for the LPP as a model of learning in an authentic learning environment.

We began this paper arguing that the key to understanding interest development in the context of out-of-school engineering programming was to examine the way in which newcomers are enculturated into a community. This statement was based on concepts of the FPMID which propose that in order for emerging individual interest to develop, those individuals need increases in knowledge and value for the domain, which requires some support^{19,7}. Our argument was that this support may come in the form of enculturation to a community of practice via classic apprenticeship methods^{26,27}. Evidence from this study supports this claim.

We found that the students examined for this study closely fit the roles of newcomer and old-timers in the community of practice, and these same students mapped closely to the trajectory of interest development described by the FPMID. Walter, who began with the Acrobots three years

ago as a newcomer with emerging individual interest, has become an old-timer in the community while simultaneously deepening his interest in engineering into a well-developed individual interest. Eli, who began this year as a newcomer with emerging individual interest, moved closer to the center of participation while also deepening his emerging individual interest. Lucas also began this year as a newcomer with emerging individual interest. His progress away from the periphery of participation was limited but detectable, and his emerging individual interest deepened as well. We believe that this provides some evidence to establish a link between LPP and FPMID; as newcomers become old-timers, interest is developed. We believe that this is an important link between the two theories included in our framework. Support for the newcomers to become enculturated into the community of practice provided them the opportunity to increase knowledge, deepen their existing value, and engage in authentic practices of the community, all important according to the FPMID in developing interest in a domain. This is also a method of assisting newcomers as they progress from legitimate peripheral participation towards full participation in the community. Again, we see this as an important parallel between the two theories. Legitimate peripheral participation is a way to allow those with emerging individual interest access to authentic learning opportunities. As knowledge and value increase, the person's level of participation can increase and this contributes to interest development. Further engagement spawns a deepening of knowledge and value that eventually allows for full participation in the community and is the basis for well-developed interest. We have demonstrated this link by showing increased interest in engineering occurring in parallel with increased participation in the Acrobots community of practice. In this case, the method of support for the newcomers came in the form classic apprenticeship methods. Our old-timer employed both modeling and scaffolding techniques in order to allow newcomers the opportunity to engage with the activity of the community.

We now look at how understanding the relationship between individual interest development and socio-cultural theories of learning have practical significance. As stated previously, there is a recognized need to increase student interest in engineering and technology in order to fill the need for these jobs in the future^{1,2}. We believe that we can provide program managers and developers guidelines for designing an out-of-school engineering program that is successful in developing interest in engineering, through analyses such as this study on the Acrobots, who, based on increases in FPMID scale scores, have demonstrated the ability to achieve this aim. The Acrobots programming group organizes enculturation into their community of practice by providing supports for newcomers consistent with classic apprenticeship. Early on, newcomers engage in legitimate peripheral participation, and at this stage the Acrobots used modeling as a method to teach these students. The specific modeling techniques used by the team include explaining existing work (e.g. Walter explaining the basic drive train code) and to encourage newcomers to observe old-timers as they produced new work (e.g. Lucas watching over Walter's shoulder while he wrote code for the robot). Over time, as an individual's knowledge and skills increase, they are able to participate more fully, but need scaffolding to do so. Acrobots used scaffolding methods such as providing completed work to be interpreted by the newcomer (e.g. Eli adding comments to code already written by Walter), and simplified tasks which can be done by combining already finished work (e.g. Eli writing a more basic version of robot code using piece of code already written by Walter). These methods help develop newcomer domain

knowledge and skills, which allows them to begin to participate more fully. It also is known to contribute to deepening individual interest. We also recognize that the old-timer from the Acrobots deliberately set out to enculturate newcomers. This is an essential component of the Lave & Wenger⁶ model of communities of practice. Without old-timers acting in this way, it is more difficult for newcomers to gain access to full participation or increase knowledge and value for engineering, and this can smother emerging individual interest in a domain¹⁶. Programs may benefit from having their learning environments structured to address the developmental needs of the students to increase their interest in a domain.

Program managers and designers are typically charged with developing the high level pedagogical approach for their out-of-school programs, as their staff work more directly with students on a daily basis. Based on our findings, if a goal of the program is to increase student interest in engineering, we recommend that program managers think developmentally, and train or guide their staff (mentors, coaches, teachers, etc.) to see this way. The staff should understand that interest develops through increased knowledge and value of a domain that proceeds along established lines (described by the FPMID), and that transitions of development often depend a great deal on the nature of the social exchanges that happen in the club. For example, like the students we observed for this study, old-timers may take newcomers under their wing and through modeling and scaffolding assist in the newcomer's enculturation into the community. This makes old-timers less efficient in their work in the short term, so they may need encouragement to do so, but attending to the developmental needs of newcomers increases interest development of the group as a whole, and this benefits the community in the long run. This is the basis of the socio-cultural learning theory that conceptualizes these behaviors at the group level, rather than exclusively at the individual level. In this study, we have provided a great example of successful implementation of these guidelines. Out-of-school programs that intend to increase interest in engineering, would benefit from instructing staff in student interest development needs. In turn, staff could then better support old-timer students in their communities in successfully enculturating newcomers into the community. Without this support, students with emerging individual interest may not find an environment that meets their developmental needs.

While we believe our in-depth mixed-methods study of interest development in engineering makes a positive contribution to the field, several limitations do exist. First, our study only includes one group within one team participating in one national out-of-school engineering program. This team was chosen because they represent an exceptional example of the program, and the specific group was chosen because the relationship between three of their students were exemplary in illustrating the team dynamic. Research at this depth must focus in on a very small sample, but in order to generalize our findings, broader scale empirical research must be conducted. This limitation would be addressed by further research which observes multiple teams, multiple programs, and/or multiple domains. A further limitation of choosing to examine this specific programming group is that there were no female participants in this group who met our inclusion criteria. Future work should address this limitation by deliberately seeking out groups that include female participants to gain more insight into any role gender may play in socially supported interest development in engineering. Another limitation is the length of time

we spent observing the group. While we captured a large amount of the activity of the team, we were not able to attend every meeting, and so may have missed some key events that could change our interpretation of what we saw. We believe our sampling method to be sound, but our conclusions would be further strengthened by a similar study that is able to observe all meetings for a group, and for a greater length of time (possibly several years). A further limitation to the study is the underpowered results from our FIDES interest survey due to a small sample. To further substantiate the effectiveness of the FRC program and of Acrobot's more specifically, a larger group will need to be surveyed. Consequently, our use of the FIDES scale score in this study is only useful as a compliment to the observational and interview data. Finally, our study is limited in not exploring how newcomers who are at the very edge of the periphery seemed to have disengaged from the programming group once the competition season began. A future study which focuses on students who disengage, particularly while remaining on the periphery of activity, would help to illuminate this gap in our study and the literature.

In summary, mixed-methods research that considers interest development through a socio-cultural learning perspective is rare²⁹. Utilizing survey responses, interviews and video recorded observations, our study contributes to this research area by providing a small, in-depth investigation suggesting participation in a community of practice as a mechanism for the development for interest in engineering.

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Appendix A: Semi-structured interview protocol.

FPMID line of inquiry

What is engineering to you?

Do you enjoy doing engineering type work?

Would you want to be an engineer?

Where do you rank, compared to classmates, in how much you know about engineering?

How confident are you in your ability to learn about engineering?

Previous background with engineering line of inquiry

Can you describe the first time you did something that you'd consider engineering?

How old were you? Why did you do this?

Do you have any engineers in your family?

Has that influenced your interest in engineering at all?

Do you talk with your family about your work in engineering or robotics?

Do your friends have any influence on your interest in engineering?

FRC participation line of inquiry

Why did you join this FRC team?

How long have you been with the FRC team?

Why did you continue to participate?

What is your role with the team?

What did you do in this role?

What was your experience with this type of work before joining the team?

What did you learn a lot about this this year?

Since you've been a part of the FRC team, has it influenced your interest in engineering?