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RESEARCH REPORT

Excessive Mentoring? An Apprenticeship Model on a Robotics Team

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Abstract: *Participation on a robotics team affords students the opportunity to learn science and engineering skills in a competition-based environment. Mentors on these robotics teams play important roles in helping students acquire these skills. This study used an apprenticeship learning theory to examine how mentors on one high school robotics team contributed to students attaining the knowledge associated with designing and building a robot for competition. How active of a role did mentors play on their competition-based robotics team? How did mentors and students together handle the challenges they faced? The mentor-student interactions detailed in the research revealed an apprenticeship model where mentors played leadership roles reluctant to move beyond modeling tasks to students. The mentors' roles bring into question if they were granting their students the full opportunities to develop skills associated with working on a robot. Despite these developmental concerns, the students on the team gradually took up simple tasks working side-by-side mentors, saw expert engineers model professional habits, and expressed being inspired while contributing to a winning team.*

Keywords: *Apprenticeship, mentoring, out-of-school time, robotics*

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Introduction

Participation in robotics related activities points toward a potential for positive student outcomes in learning science and engineering skills (Benitti, 2012). Robotics is seen by some as a vehicle for learning and understanding new technologies (Barker, 2012) as students acquire engineering design (Ahlgren, 2002), electrical and mechanical engineering (Barak & Zadok, 2009), and programming (Williams, 2003) skills. Furthermore, robotics activities provide a hands-on experience (Mataric et al., 2007) that improves students' systems thinking (Sullivan, 2008), promotes scientific inquiry (Robinson, 2005), and increases awareness of scientific and engineering careers (McGrath et al., 2009). Adult mentors play instrumental roles on robotics teams by guiding students toward gaining scientific and engineering skills and supporting them through challenges brought on by robotics competitions and programs (Barron et al., 2008). This study examined mentoring, and the associated student behavior, on one robotics team where adult mentors used robotics as a means of passing down expert knowledge and engineering skills to a team of high school-aged students.

Mentoring is seen as an important factor in the development of less experienced individuals in many engineering and science fields. The mentoring process has been defined as a series of interpersonal exchanges between a more experienced individual providing support and guidance to a less experienced individual (Baugh et al., 1996; Spencer, 2006). Mentors can provide mentees with opportunities to take part in team building, brainstorming, and planning sessions (Russell, 2006) that contribute to the overall continuous learning processes within the engineering and scientific professions. Mentors can also create challenging and participatory learning environments (Atkins & Williams, 1995; McKinsey, 2016), provide feedback and suggestions for improvement (Quinn, et al., 2002), and integrate new members into social networks within an organization (Wallace, 2001) for their mentees. The mentoring process of giving advice and support has also shown to enhance a mentee's level of confidence and self-efficacy in their vocation (King et al., 2009; Kram & Isabella, 1985), including within engineering (Wallace & Haines, 2004). Students with mentors have the opportunity to observe their mentor being successful and assimilate these attitudes, behaviors, and values into their own practices (Fairbanks et al., 2000; Speizer, 1981).

Mentoring influences and impacts can also play out in out-of-school time (OST) robotics teams. A widely known, international robotics competition defines mentoring in a similar fashion: a process in which an experienced person provides guidance, support, and encouragement to a less experienced person (FIRST Mentoring Guide, 2007) in the context of designing and building a robot for competition. Mentors on these robotics teams have the potential of creating a challenging and participatory learning environment that promotes team building and work ethic while increasing students' level of confidence and self-efficacy in strategizing, designing, and building a robot.

This case study presents an approach used by mentors attempting to pass down scientific and engineering skills to their students on a robotics competition team. The findings from this study have the potential of contributing to the larger body of mentoring literature by describing one example of mentoring occurring in an OST environment. Additionally, the findings may inform researchers and practitioners in OST science, technology, engineering, and mathematics (STEM) education fields of some types of mentor-student interactions that take place in competition-based environments, and further the discussion of how the level of directive mentor involvement may impact student development in OST STEM programs.

The authors sought to address the following research questions:

1. How were mentors involved in helping their students through the processes of designing and building a robot for competition?
2. How did students behave and respond to their mentors' involvement?

Framework

This study turned to two learning theories to help illuminate the mentor and student experiences during their robotics season: traditional apprenticeship learning and cognitive apprenticeship learning theory. These two educational learning theories provided the authors with a lens with which to gain a greater understanding of how mentors and students on this single robotics team, which is referred to as Team Edison, worked together to accomplish their goals of designing and building a robot for competition.

Traditional apprenticeship

Traditional apprenticeship learning is often associated with on-the-job training of an apprentice becoming competent in a skill or craft that, in turn, contributes to the overall manufacturing and skilled labor workforce (Ainley & Rainbird, 2014). However, apprenticeship learning can be applied to less industrial contexts, including in OST robotics programs where mentors are guiding students how to use programming and construction tools. In apprenticeship learning, the apprentice is within close proximity of the context of practice (Johnson & Pratt, 1998) working side-by-side an expert mentor (Barab & Hay, 2001) learning a set of procedures or a specific skill. Traditional apprenticeship learning is known to have four stages: modeling, scaffolding, fading, and coaching (Collins et al., 1991).

In the modeling stage, the expert mentor demonstrates all of the desired learning goals and processes in front of a closely watching apprentice. In apprenticeship learning theory, most

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of the learning occurs during the modeling stage (Lave & Wenger, 1991) as the apprentice observes the requirements needed to successfully compete the task. In addition, the apprentice sees how an expert attack a real world task or problem without false starts or dead ends (Idol & Jones, 2013).

During scaffolding, the expert mentor provides varying levels of support as the apprentice begins to take ownership of the task. The level of support given by the mentor depends on the apprentice's zone of proximal development (Vygotsky & Rieber, 1988), or the difference between their ability to accomplish a task without help and their ability to complete a task with help. In this stage, the mentor must be aware of how much support the apprentice needs in order to successfully complete a task and progress forward in their learning. Providing too much support may prevent the learner from taking up tasks, while providing too little support may lead the learner to failure.

In fading, the transfer of responsibility from the mentor to the apprentice nears its completion. The master and apprentice continue to work side-by-side as the apprentice becomes more comfortable and confident in their ability to complete the tasks at hand. The master steps away from the master-apprentice interaction upon seeing the apprentice successfully complete the tasks, which then allows the apprentice to work independently.

In coaching, it is not so much a stage as it is constant monitoring by the expert mentor as their apprentice moves through the apprenticeship learning experience. The expert mentor monitors the apprentice's learning throughout by providing feedback, asking questions, offering encouragement, and challenging them with new tasks. The stages and aspects of traditional apprenticeship learning carry important implications for how learning can occur when a novice is learning new skills and content. As data were collected and analyzed, traditional apprenticeship learning theory was drawn upon to guide the understanding of how mentors on Team Edison were passing down skills and content to their students as the team designed and built their robot for competition.

Cognitive apprenticeship

It is important to note that traditional apprenticeship learning, where an apprentice learns under an expert's tutelage, can be enhanced to reach deeper cognitive levels in what is referred to as cognitive apprenticeship (Collins et al., 1989). In a cognitive apprenticeship, practitioners or expert mentors actively work to help the apprentice better understand the reasoning behind why they perform tasks in certain ways and how the work relates to other settings and contexts. More specifically, expert mentors make their thinking visible by pointing out possible pathways at decision junctions, best choice and practices at these junctions, and problems that could arise if certain actions are taken (Collins et al., 1991). Cognitive apprenticeship can allow the apprentice to understand the purpose of the knowledge they are learning, become informed about the

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different contexts in which the knowledge can be used, and ultimately use or apply the knowledge as opposed to passively receiving it (Dennen & Burner, 2008). As this model can help apprentices develop valuable higher-order thinking skills, this case study was particularly interested in the extent to which this style of cognitive apprenticeship occurred, if at all, on Team Edison. As the study drew upon traditional apprenticeship learning, it also drew upon cognitive apprenticeship to guide further understanding of how mentors and students were interacting with each other as they worked side-by-side in their science and engineering workspace within an OST robotics competition-based activity.

Methods

Team Edison was examined as a qualitative case study investigating their mentor involvement, mentor-student interactions, and associated student behavior (Hartley, 2004; Rossman & Rallis, 2012). One-on-one interviews and first-person observational data were collected during the same robotics season over the course of four months. The process of choosing Team Edison as the point of study involved a whittling down of ten other teams based on the degree of directive mentor involvement in the day-to-day decision making process of the robot design, construction, and implementation. Based on the findings of the larger study, Team Edison stood out as having high directive mentor involvement when it came to these decision-making areas. In addition, Team Edison aligned with educational learning theories in which students were learning and gaining experience from their mentors through an apprenticeship learning environment. For these reasons, Team Edison was chosen as a case study to examine how mentors were involved in passing down scientific and engineering skills to their students, and how their students responded on their robotics competition team.

It is important to note that all three authors have had experience mentoring students in OST science and engineering competition programs. Both first and second authors were public high school science teachers and organized OST STEM programs for their students. The third author has had experience being a lead mentor of an elementary and middle school robotics team for seven years. These experiences provided all three authors with a working knowledge and understanding of the framework of an OST competition program.

Participants and team settings

Pseudonyms were used for the names of the mentors, parents, students, and the teams who participated in this study. Team Edison consisted of 30 high school student members and 15 mentors. The Team Edison mentors were comprised of mechanical engineers, machinists, retired teachers, and computer programmers. Many of them held full time positions in local engineering and technology firms, but volunteered their time to help Team Edison in the afternoons and

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evenings. The lead mentor, the only teacher amongst the mentors, taught several computers programming courses at the high school, and led the overall operations of the robotics team after school. She held a bachelor's degree in information technology and an MBA from a university located in the northeast Atlantic area of the United States. Students joined the robotics team for a variety of reasons, including liking science and engineering, preferring competition-based activities, and wanting to be with their friends. All students who expressed a desire to be on the team were welcomed to join.

Team Edison was located in a suburb of a large city in a central Atlantic state. This veteran team of seven years was a school-based team, meaning the robotics team was an after-school extra-curricular activity option for all attending high school students. The team worked in a set of three rooms within the high school. The three rooms consisted of a large computer lab with several whiteboards for design discussion, a workshop with equipment and tools used for construction, and an open room where replica pieces of the game were housed and used for practice. The design, programming, and marketing teams spent most of their time in the computer lab. The build team received information from the build and programming team, but spent their time in the workshop. The large open room was used as more finished robot products needed to be tested.

Team Edison engages in an annual competition administered by a not-for-profit company. This company develops a different game each year where thousands of teams around the world create their own robot to play in the game. While the company mergers STEM content, sporting competition, and pop culture into the design of their annual games, their goals are more focused on youth development. Their central mission is to inspire K-12 students to enter careers and be leaders in STEM fields by engaging them in mentor-based robotics programs that build scientific and engineering skills and encourage innovation.

Each robotics team competing in this event, including Team Edison, was given six weeks to design and build a robot. Team Edison met every day after school for three to four hours. The game rules do not require teams to build the same robot but rather provides opportunities for teams to develop their own strategies and robot designs. This made for multiple variations of robot strategy, design, and construction across the entire robotics landscape. Upon registration, teams are given the minimal amount of materials to build a robot, such as motors, metal, and wheels. However, teams could spend up to thirty-five hundred dollars on additional materials to enhance their robot. Veteran teams had a material advantage over more rookie teams as they had accumulated materials and resources from prior years. Teams were required to enclose their robot in a giant plastic bag and time tag it at the end of the six-week build season to ensure fairness. These bags were then checked at regional competitions as a method of monitoring any wrongdoing.

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In the year of this study, the robotics game involved scoring points in two separate ways on a 27 by 54-foot field. Teams could design a robot to pick up foam basketballs off the ground and shoot them into one of four baskets located on both ends of the field. They could also score points by designing a robot that balanced on a teeter-totter bridge located in the center of the field. Most teams designed their robot to score points in both methods. In each match, a three-team alliance competed against another three-team alliance. Individual teams were placed on a different three-team alliance for each proceeding match in order to play with and against most teams in the competition. Individual teams prepared for their next match in their assigned pit area away from the playing field. In the pit area, mentors and students made adjustments and preparation to their robot in order to be ready for their next match.

Team Edison's robot design included the ability to drive straight over foam balls on the ground, scoop them up into a vertical conveyor belt made of surgical tubing, and shoot them out the top of the robot from a single spinning wheel. The balls were forced out the top of the robot from being wedged between a curved piece of metal and the spinning wheel. As the balls left the robot, they had a backspin that was advantageous for shoot balls off a backboard into a basket. Additionally, the robot possessed a camera atop their shooting apparatus to recognize the reflective tape on the basketball backboards in order to align and shoot accurately.

The not-for-profit company goes to great lengths to make the competition events just as exciting as the build challenge itself. Dozens of regional events are played around the world as teams choose which ones to attend. Teams may attend more than one regional if they have the budgetary means. Team Edison participated at two regional competition events, each consisting of approximately 60 teams. Team Edison also competed at the world championship event due to winning the "best overall team" award at one of the regional competitions they attended. Four hundred teams competed at the world championships.

Data sources and analytical approaches

The authors sought to shed light on a "contemporary phenomenon in a real-life context" (Yin, 2009, p.73), which is appropriate with descriptive case study methodology collecting data through direct observations and in-person one-on-one interviews. In attempting to compare data to a framework, the authors searched for matching patterns between the traditional and cognitive apprenticeship learning theory frameworks and the mentoring styles and associated student behavior data. While data were compared for similarities with the learning theory frameworks, analysis also looked for contradicting data. The type of triangulation took the form of data triangulation (Bryman, 2011) from sources such as observations, interviews, and student artifacts in order to increase the validity of the study.

Observations were recorded to capture events, actions, and interactions made by mentors and students on Team Edison as they designed, built, and competed with their robot.

Observations focused on aspects associated with how Team Edison made decisions and completed tasks during the build and competition season: mentor involvement, mentor-student interactions, and student behavior and actions. The observations were made during the team's six-week build season, over two regional competitions, and at the world championships. Team Edison allowed the authors full access to team meetings during the build season as mentors and students completed tasks in their respective workspaces, held large and small group discussions about progress being made on the robot, and addressed issues that arose during the team's progression. The public nature of the regional and world championship competitions further allowed authors to gather close observations and data. This overall embedded approach produced a comprehensive data collection generating thick descriptions of the social processes that took place between the mentor and the students on Team Edison. Eight hours were spent observing Team Edison during the build season. The team was further observed at two regional events during the competition season. Sixty hours were logged observing the team over four days at two regional events and over three days at the world championship event.

Interviews were also conducted to gain an in-depth understanding of Team Edison's season progression. Specifically, the aggregate of individual mentor and student perspectives from these interviews helped elucidate mentors' role and involvement, mentor-student interactions, and student responses to their mentors' directive as the team progressed through designing, building and competing with their robot. Interviews were conducted on a one-on-one basis using a semi-structure approach (Drever, 1995). A list of prefigured, open-ended questions was developed to explore topics related to answering the case study's research questions. However, the interview process remained open to pursue topics the mentors and students brought up during questioning. All interviews were conducted during Team Edison's build season meetings and at competitions in order to capture real time data: mentors and students not far removed from their work. The lead mentor and four additional mentors were interviewed. Six students from Team Edison were also interviewed. Two students were chosen by the lead mentor to be interviewed, for they, as she pointed out, held leadership positions on the team. The other four students were interviewed at the world championships and had various positions on the team. The interview format began by requesting interviewees to explain the robotics game, share their team's strategic approach, and describe their robot design. These initial requests allowed interviewees to display their knowledge of the game and their team's direction moving forward. Then, the interview progressed into questions regarding the team's organizational structure and their role on the team. Questions in this part of the interview explored how the team was structured, what their individual roles were on the team, what their motivation was for joining the team, and how knowledge was passed from mentors and advanced students to more novice students. Additionally, questions in this part of the interview asked interviewees to

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describe the mentor philosophy and involvement, and how the mentor involvement influenced the organizational structure and day-to-day functionality of Team Edison. The final part of the interview looked into how the robotics competition influenced their own development. These final questions explored what interviewees gained from participating in the robotics competition, how the robotics competition had influenced their career views, and how they judged their performance at the end of the year. All interviews were recorded, transcribed, and confirmed by the interviewee to ensure accuracy of what was said in the interview.

The act of combining the traditional and cognitive apprenticeship learning theory frameworks created two themes that were used to organize, analyze and explain the data to support answers to the research questions. The two themes were *boundaries and objectives* and *apprenticeship stages*. Coding for the theme *boundaries and objectives* involved combing for descriptions in the data of mentors and students describing their goals, objectives, working boundaries, and level of involvement during decisions made on the robot strategy, design, and construction. For example, if a student described in an interview their role on the team, then this was coded as *boundaries and objectives*. Coding for the theme *apprenticeship stages* involved combing for data describing how knowledge and skill development was being passed down from the mentors to the students. Furthermore, coding within this theme looked for descriptions of the modeling, scaffolding, fading, and coaching stages as well as mentors providing reasoning behind why they performed tasks in certain ways during these transfers of knowledge situations. Evidence from these two themes was used to answer the stated research questions.

Findings

The following section presents the research findings as they relate to how mentors were involved on Team Edison in helping their students through the processes of designing and building a robot for competition, and how students behaved and responded to their mentors' involvement. In the first "Build Season" subsection, the two themes (*boundaries and objectives* and *apprenticeship stages*) are discussed along with evidence to answer the research questions as mentors and students worked to prepare their robot during the six-week build season. In the second "Competition Season" subsection, the two themes are, again, discussed in relationship to the research questions as mentors and students participate in the two regional competitions and at a world championship event.

Build season

Team Edison experienced the same intense challenge as every other team in the competition to develop a game strategy, create a robot design, build their robot, and be ready for competition within a six-week time period. The analysis of Team Edison during their build season

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revealed mentors playing active roles while creating a structured learning environment that allowed students to follow specific steps and assigned tasks. The working environment, influenced by the mentors' professional engineering background and the competitive nature of the robotics activity, afforded students opportunities to acquire skills in a more procedural manner while observing a robot being designed and built as it was intended. These findings mostly aligned with the traditional and cognitive apprenticeship learning theory frameworks as mentors modeled and scaffolded (Collins et.al., 1991) desired learning goals and processes to their students while providing reasoning and context to their decision making. However, latter stages of apprenticeship did not materialize as mentors were found reluctant to fade from students working on vital steps of the robot's design and construction. The learning theory frameworks are continued to be referred to as the findings are discussed and interpreted within the two coding themes.

Boundaries and objectives. The mentors on Team Edison believed their roles were to model proper design and construction techniques, create a workspace that resembled working in an engineering-like environment, and pass down their expert knowledge to the students. They believed that developing a robot design and constructing it provided them with a medium to show and teach students science and engineering skills. The mentors' expressed beliefs aligned closely with what we expect to see in apprenticeship learning theories (Collins et al., 1991) as expert mentors begin passing down knowledge and skills by first, modeling best practices and then, allowing students to slowly take over responsibility through guidance and scaffolding. Karen, the lead mentor, best illustrates the overall role that mentors play on Team Edison:

> Having mentor involvement on our team allows students to get an understanding of building a working robot. The mentors show them how things are done in the way they are intended to do. They are the experts. They show them and the students see how things are done by the experts.

A further description of the mentors' involvement entailed them wanting to broaden their student's understanding of scientific and engineering workplace habits as a whole. Their goals were to showcase a working environment that resembled how engineers work together in the hopes that these habits would trickle down to the students. Justin, a mentor of three years, describes this more detailed role of a mentor on their team:

> I think our role is to show habits of being an engineer. You know, come up with a design and a prototype. Test things out. Rethink a design before building a final robot. We want to show these habits and show what it is like to be an engineer and work with other engineers. I am hoping by showing these habits that they'll begin using these habits themselves.

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Mentors on Team Edison also wanted to share their own personal expertise as a way of contributing to the team. Many of them viewed themselves as a liaison, or a link, between what is happening in the real world of science, engineering, and technology and what their robotics team was trying to accomplish. Mentors felt that students were not only learning new skills from them, but also learning up-to-date techniques and information. Ken, a mentor of two years, shares this view of contributing to the team:

> I have had experience working with a similar shooting device as we have on our robot, and I know other mentors have other experience too. Part of our job is passing down what we know and what we know how to do to the students. If I have worked with some new equipment or technology, I want to make sure I share that with the team so they are familiar with it too.

In addition to sharing their expertise, the mentors held a desire to expose their students to all areas of robotics team, which included the build, programming, electronics, design, drive, marketing, website, and community outreach sub teams. They believed having their students spend at least some time in each area would help the students create a broader picture and understanding of how an organization worked. To ensure this happened, mentors rotated students around from sub team to sub team when they felt like the student had learned enough or became comfortable with responsibilities within their current sub team. Grant, a student in his fourth year on the team, shared the rotating process and its effects:

> The lead mentor's goal is to push you out of your comfort zone. She puts you into other groups once you have become comfortable in an area. I was on the build team for a while and then I got moved to help with our team's presentation. I am not good at speaking in front of others but it did help me get better.

While there was high directive mentor involvement on Team Edison, there was willingness on the mentors' part to share and teach design and construction skills to their students. Furthermore, the students on the team had a positive reception to the approach the mentors were using in their day-to-day operations. Abby, a high school senior and three-year veteran student, supports this positive attitude toward the mentors' approach:

> We get to see expert mentors right in front of us work and we get to see and learn from professionals in the way things are supposed to be done. They come right from their jobs to here and help us. Then we get to drive this amazing robot at competitions.

The students described their experience on the team as working collaboratively with their mentors, being exposed to increasing challenges, and seeing how things are done properly by

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professionals. Sean, a three-year veteran student, explains the process of how mentors and students work together:

> They work side-by-side us, which I think is good. They work with us and they treat us as their peers as opposed to being completely far removed and saying, 'We're not going to touch the robot. You guys go do your thing.' It's more like they work alongside us as team members almost which is really cool because obviously, they have more knowledge.

Some students provided detail as to how they were incorporated into more mentor initiated tasks, as shared by Sean in the previous statement. This mentor-student exchange continued as students became more familiar and confident with the task at hand before receiving more difficult challenges. These stated descriptions from the students align with early stages of apprenticeship learning theories as expert mentors demonstrate what they are working on while simultaneously enfolding less experienced students into working on the robot and expecting the students to begin learning the displayed skills so that they can eventually accomplish the tasks on their own. Ryan, a four-year veteran student, confirms these early stages of apprenticeship of students being brought into working on the robot and being given more responsibilities:

> Once you get comfortable with what they are showing you, you're given more to do. As you get more experience you start greater and greater tasks, but they are not going to give something that is way over your head to begin with but they are going to challenge you.

Along with having a positive disposition toward how mentors were interacting with them on their robotics team, many students appeared to echo the mentors' own definition of involvement. Students expressed that they were watching and learning how things were done correctly by professionals. Ben, a rookie team member, states this exactly: 'We get to see how things are done by the mentors and learn from what they are doing.'

Statements made from mentors and students on Team Edison regarding characteristics of their roles and involvement were in parallel with each other, appeared to not generate any conflicts, and mirrored apprenticeship learning theories of mentors modeling learning goals before students were integrated into the working process. Mentors acknowledged that they were the ones passing down vital information for their team to be successful. The students agreed with this process of first, watching expert mentors and then, slowly taking up responsibilities to become more integrated on the team.

Apprenticeship stages. The mentors on Team Edison created a structured learning environment that had students following procedural steps to acquire skills. These observational findings aligned with early stages of the apprenticeship learning theory framework as mentors

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modeled and scaffolded desired learning goals. Though, as these mentor-student interactions continued, mentors failed to fade and allow the students to work independently particularly when it came to tasks pertaining to the robot's design or construction. The highly active role and presence by the mentors caused a deviation away from the apprenticeship learning theories.

To illustrate mentors not completing the stages of apprenticeship learning by not giving students the freedom to work independently, the findings turn to an interaction that occurred between one of the build team mentors and a student after the mentor discovered a problem with their robotics frame.

Bill, one of the build mentors, noticed part of the frame needed some small reshaping in order for it to fit around the electronics board and drivetrain. Specifically, there were eight metal corner pieces that had a curved inside to them that needed to be reshaped. Once corrections were done, these pieces were to be fitted onto long horizontal and vertical metal pieces to make the lower section of the robot frame. Bill gathered the eight metal pieces and asked Max, a build team student member who had just finished listening to another mentor explain how the shooting apparatus would work, to join him at the bench grinder. Bill asked Max if he had used a bench grinder before. Max shook his head 'no.' In response, Bill nodded and told Max that they were going to reshape the corner pieces for the robot's frame. Bill placed the first corner piece on the tool rest in front of the grinding wheel and asked Max to watch closely because he wanted Max to be able to do it on his own. As Bill began to model how to grind down the curved corner piece, he began to orally explain what was happening. He referenced the angle the tool rest was set at and speed of the wheel as the metal receded from the grinding. When Bill finished making a more right angled corner piece, he pointed to other parts of the bench grinder to explain its scope and uses, including polishing metals and sharpening tools. Then, he said to Max that he'd like him to try grinding the next piece. Bill stood next to Max and gave specific instructions in order to replicate the second piece to match the first corner piece. Once Max finished, Bill took the metal piece and compared it with his piece to check if they lined up. This interaction of Bill guiding Max through the grinding process and then checking Max's work repeated itself with the remaining six pieces.

Several components of traditional and cognitive apprenticeship learning (Collins et.al., 1991) were present in the interaction between Bill and Max. Bill began by asking Max his level of familiarity with the bench grinder. This allowed Bill to gauge where to start and how much he needed to explain. Bill then took the time to orally describe what was occurring and the reasoning behind his approach while simultaneously modeling grinding the corner metal piece. In this early part of the interaction, the modeling of tasks by an expert mentor occurred while a novice stood by watching and learning (Lave & Wenger, 1991), as seen in traditional apprenticeship learning. An expert mentor was also observed adding context to the task by making the reasoning behind his actions visible and providing a broader scope of the equipment's uses (Collins et al., 1989), as seen in cognitive apprenticeship learning. Then, the interaction moved into the next phase as Bill and Max switched positions. Bill provided scaffolding and direction as Max completed the task of grinding the second corner metal piece. This scaffolding component is present in apprenticeship learning as a novice begins slowly taking ownership of the task in the presence of an expert mentor. The interaction continued as Bill remained working side-by-side Max providing constant guidance and advice. In this final phase of the interaction, the expert mentor did not fade to allow the novice apprentice to work independently. Here, a deviation away from the expected latter apprenticeship stages occurred as the mentor was reluctant to fade, and instead stayed to ensure each step was performed correctly. The skills learned by the student in this interaction focused on becoming accustom to using the equipment or tool, but did not expand to an application of skills in other contexts. Finally, the interaction runs parallel with statements made by both the mentors and students: a mentor brought in a student to show him what he was working on; a mentor modeled the task before challenging the student to perform the task himself; the mentor and student worked side-by-side.

This deviation from later apprenticeship stages repeatedly played out in mentor-student interactions that involved working directly on the robot's design and construction. However, all apprenticeship learning stages occurred in mentor-student interactions on Team Edison in areas not directly impacting the robot's design and construction, such as on the marketing and website development subteams. The following interaction displays how mentors faded from a group of students to allow them to work independently.

Karen, the lead mentor, was discussing with three students about the importance of marketing the team at the competitions so that when it came time for the elimination rounds there was a greater likelihood that their team name would be mentioned in conversations. Karen started showing them how to make team buttons that would be used to generate brand name recognition throughout the competitions. She showed how the images were laid out several times in a Word file before printing out many copies. Once one sheet was printed, Karen took the copy and cut out one of the images, placed it between a metal button and the plastic covering, and then laid it on the button maker machine to be hand pressed. She pressed down the handle, lifted it back up, and took out the button to reveal the finished product. She then asked the students to make a couple hundred of them for the team's trip to their two regional events. As the students began making the buttons, she monitored the students' progress for two or three buttons to ensure accuracy. Finally, before stepping away, she encouraged the students to think of other creative ways of marketing the team, and reminded them of previous years' shirts and buttons. Karen moved on to another project as the students made buttons and talked openly about their ideas to further market the team. The students quickly came to an agreement that they wanted to

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stand out and be recognized but not be obnoxious or annoying in public. Several ideas were shared before they decided on a professional look where everyone would wear a short sleeved collared shirt that had their logo on it and a small fedora hat decorated in sequins and blinking lights.

Most components of traditional and cognitive apprenticeship learning (Collins et al., 1991) were present in the team marketing interaction between the lead mentor and the three students. Karen modeled making the buttons and provided some scaffolding and guidance as the students took control of the task. Karen also faded from the task allowing the students to work independently and challenged, but did not require, the students to further think of ideas to expand their marketing roles. Observations made of mentor-student interactions during the build season, and later in the competition season, saw mentors playing more active roles in decisions and tasks that were directly associated with the robot design and construction. These mentor-students interactions during decisions made on the robot design and construction focused on student learning of machinery or tool competency skills. However, students were found to take more control of tasks and generate ideas in areas of the team that did not directly impact the robot's progress.

Competition Season

Team Edison competed against approximately 60 teams at each of the two regional competitions and, after qualifying, against 400 teams at a world championship event. The analysis of Team Edison, as they prepared their robot and competed in match play, revealed mentors playing an even more active role compared to during the build season. Mentors reverted to only modeling tasks to students and abandoned giving reasoning or context behind decisions they made, revealing a further deviation from the traditional and cognitive apprenticeship learning frameworks.

Boundaries and objectives. The mentors on Team Edison continued to believe their roles were to model tasks for their students during the competition season. Mentors modeled programming and mechanical adjustments while assigning small errands and responsibilities to their students. Erik, Team Edison's pit area mentor, captures what roles mentors and students have at the competitions:

> It works out that every mentor has their role at the competition. There's so much going on to get ready for the next match that we need to assign jobs to students, but we're getting them excited about the process and problem solving of the robot by showing them so they can see how it's done and be ready for the next match.

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Students provided their perspective of being on Team Edison at the competitions as committing to mentors demands, recognizing some pressure to win, and being goal oriented and responsible for completing tasks. Abby, the veteran student, describes the student roles at the competitions:

> It is a lot of pressure because we have gone to Worlds every year since our inception. You're thrown into this place where it's like you don't really know what's going on but our mentors help guide our team and keep us on track. [Team Edison] can be competitive, and it can be a stressful environment, but it's also a family… It is competitive, but it is very much so that you're with mentors and students that you know want to be there, who you know are working hard. It can be a bit stressful, but it is a good thing because it pushes you to succeed.

Statements made from mentors and students on Team Edison about their roles during the competition season described mentors managing the team's operations. However, despite mentors playing a more active role on Team Edison, students expressed a desire to continue working in this environment. Sean, the veteran student, shares his thoughts on the team's operations:

> I'm inspired by being on this team to go into engineering. Our mentors have their own jobs in engineering but come share with us how things are done and we build a great robot that helps us get to worlds [championship]. That's inspiring to me that I get to be a part of this and makes me want to go into engineering.

As seen in the next *apprenticeship stages* section, further evidence is given that align with the observations of mentors modeling robot adjustments and preparations between matches prior to informing students of changes as they drive the robot in match play.

Apprenticeship stages. There were clearly defined roles and boundaries between the mentors and students during the competitions. Through the apprenticeship learning theory lens, mentors were observed only modeling tasks for students and did not progress to scaffolding or fading stages. Students received relayed information from their mentors about any adjustments made to their robot prior to driving it in match play. The following interaction describes the roles mentors and students played in the time between matches.

After driving their robot in match play, students would place it on a handcart and wheel it back to their designated pit area and inform the mentors of any issues they had during their match. The pit area mentor would begin checking for any damages or mechanical issues as students stood by ready to aid the mentor. If students did actively participate, it was in the form of handing a tool to the mentor or running to look for a specific part from another team. Once any mechanical repairs or adjustments were made, the robot was wheeled by the students to the practice area to check for any programming and driving errors. Both the mentors and students prepared the robot to test its ability to scoop up balls and shoot them into baskets in the practice area. Mentors checked their programming language and tested the robot's shooting ability. One or two students would stand by the programming mentors while other students fed foam balls to the robot and retrieved them as the robot kept shooting. Once the mentors were comfortable with the robot, they would relay to the student robot drivers any new information or adjustments made that would affect their ability to drive or perform properly in the next match. The students would then reload their robot onto their handcart and wheel it over to the queue for their next match. The students would drive and compete in their match and the above process would start over again.

In these between match play interactions, the mentors and students were working as a team but had clearly defined roles: the mentors prepared the robot and the students drove it in match play. In the pit area, mentors modeled best practices of how to check for and repair mechanical damages for their students. Students were not further brought into the learning process of taking over tasks, as seen in apprenticeship learning theories (Collins et al., 1991). In addition, mentors completely abandoned adding any reasoning behind their decisions and how the work related to other contexts, as seen in cognitive apprenticeship learning theory (Collins et al., 1989). Mentors and students worked together to set up their robot in the practice area before, again, mentors modeled best practices of checking for programming errors and accurately firing balls from the robot's shooting mechanism. Finally, mentors transferred information to students on a need-to-know basis before the students departed to drive their robot in the next match.

Although there were open lines of communication between mentors and students, most notably students informing mentors of problems and mentors informing students of changes, mentors spent little to no time training students or explaining how to solve problems that arose during competitions. As seen in this next interaction, mentors continue to model problem solving, but do not further engage students into either explaining the reasoning behind their decisions or developing problem solving skills.

Team Edison made some modifications to their robot before participating in their second regional competition. In addition to the camera on top of their robot that recognized reflective tape on the backboards for shooting accuracy, they added a second camera near the base of their robot to allow the student drivers to receive a live feed on the computers in front of them for better driving visibility. Unfortunately, Team Edison soon found out the addition of the second camera caused the original camera on top of the robot to lose its ability to recognize the reflective tape on the backboards while the driver camera only received spotty reception. In a lengthy delay between two of their matches, six mentors and two students were at the practice area trying to

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solve the two cameras problem. Most of the mentors focused on checking the programming language on their computers while the two students and one mentor checked the robot to see if all equipment was properly connected and aligned. After approximately twenty minutes of the mentors talking amongst themselves, they appeared to become frustrated and decided to ask for technical help from a couple of adult competition officials. The conversation that ensued occurred between the mentors and the officials as the two students stood off to the side watching and waiting. The officials diagnosed that their robot was using too much bandwidth to accommodate both cameras. They suggested, talking directly to the mentors, to either reduce the frames per second on the driver camera or to take the driver camera off altogether and drive by normal sight. The mentors decided to reduce the frames per second feed for the next match before removing the camera completely if the problem continued. The mentors then made changes and informed the students they would be receiving a slower feed in the next match. The mentors told the students to rely on the computer feed only if they could not drive by normal sight. In the next match, the issue had been resolved as Team Edison returned to shooting accurately.

This interaction highlights the roles mentors and students played in order to solve a problem. The mentors took command of the situation by checking and rechecking where they felt the problem existed. Students played a minor role early on attempting to help by voluntarily attending to the robot. As time passed, mentors decided no one on their team was capable of solving the problem so they sought out help from technical officials. Once the officials diagnosed the problem, the mentors gathered the needed information, made a decision to fix the problem, and informed the students of the change to prepare them for the next match. When seen through the apprenticeship learning frameworks, the students that were present only watched how adult mentors attacked a real world problem (Idol & James, 2013). This interaction is also in line with other observations of the mentors on Team Edison playing major roles in preparing the robot and not moving beyond modeling tasks, while students observed tasks being completed and driving the robot in matches.

The deviation from the apprenticeship learning theories was more pronounced during the competition season as mentors and students did not progress through the stages of traditional apprenticeship learning and contextual and reasoning factors of cognitive apprenticeship were not present. Regardless of whether the mentors were incorporating students into completing tasks, as seen during the build season, or reverting to only modeling tasks during the competition season, the students on Team Edison saw expert mentors moving through an engineering process that resulted in a well-built robot. These mentor-student interactions also lead to the team performing well in match play and finishing in the top 50 teams at the world championship.

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Discussion

Some may form conjectures as to why the mentors on Team Edison did not attempt to create a more self-directed learning environment, where the locus of control over learning is transferred from the mentors to the students (Abdullah, 2001; Kerka 2000): the mentors desired to win in the competition-based robotics activity; the time constraints prevented in-depth learning; the adults lacked the pedagogical knowledge to further engage students in learning more complex design and construction tasks. Regardless of such speculation, the mentors on Team Edison maintained their position that student learning would mostly occur through their own modeling of design and construction techniques, workplace behavior, and decision making processes. This centralized focus on modeling can have positive workplace results. Modeling is an instructional strategy in which an expert demonstrates a new concept or approach to learning (Eggen & Kauchak, 2001). It allows expert mentors to engage their students in imitation of particular behaviors that complete tasks successfully and encourage learning. Modeling also helps mentors measure the difficulty of the task by giving focus to their students in what is expected of the workload and behavior (Haston, 2007). As Bandura states (1977), learning would be exceedingly laborious if people had to rely solely on the efforts of their own actions to inform them of what to do. In addition, effective modeling optimizes the chances of students having a successful learning experience (Biggs & Moore, 1993).

It appeared the students on Team Edison were in agreement with the more modeling approach used by their mentors. The associated student behavioral gains on the team were foundational workforce characteristics, including an acquisition of basic knowledge and skills, a recognition of accurate techniques and decisions, an awareness of their potential success, and an inspiration to further develop themselves in their field of choice. The mentors approach provided their students an insight into how professional scientists and engineers successfully complete tasks in designing and building a successful robot. The mentors also created a working environment where students were compliant with the assigned tasks given to them. In turn, the student experiences on Team Edison inspired them to continue to pursue their interest in STEM related fields: a central mission of many OST STEM programs.

In contrast to the initial benefits of modeling, the mentors' actions of deviating from apprenticeship learning limited students' further development beyond acquiring basic science and engineering skills. Students were given opportunities to observe their mentor being successful, but were provided with few opportunities to assimilate these attitudes, behaviors, and values into their own practices (Speizer, 1981), especially when working directly on the robot. The students participated in a hands-on experience (Mataric et al., 2007), and became more aware of scientific and engineering careers (McGrath et al., 2009). However, students were rarely given opportunities to explore their own robot strategy and design ideas. Mentors integrated students into the social and working networks within the team (Wallace, 2001), but only created a participatory learning environment that involved following directions with little need for providing feedback and suggesting improvements (Quinn et al., 2002).

Hovering, a technique mentors on Team Edison used to ensure accuracy, is an over-involvement of a parental or authority figure in a young person's life with the goal of avoiding negative consequences (Ginott, 2003). The mentors on Team Edison continued to hover and make important decisions throughout the build and competition season, thus protecting students from dire failure. This raises long-term developmental concerns, as students who report over-involvement of a parent or authority figure in their lives also report significantly higher levels of anxiety (Reilly & Semkovska, 2018) and lower levels of confidence when attempting to manage life's stressors (Bronson & Merryman, 2009). Furthermore, students who report having an over-involved parent or authority figure are related to extrinsic motivation to learn, perfectionistic discrepancy, and avoidance goals for learning (Schiffin & Liss, 2017), which have been associated with lower academic performance.

Grit, defined as a non-cognitive trait associated with perseverance and passion for long-term goals (Duckworth et al., 2007), is stated as an important personality indicator to determine one's ability to work through obstacles and challenges. An individual who possesses grit persists when faced with adversities, and those that face adversity and setbacks are said to reach higher levels of strength, fulfillment, and personal development (Haidt, 2006). The students on Team Edison were not given opportunities to work through difficult challenges, and thus concerns are raised about their long term ability to problem solve and sustained interests toward STEM careers. A parent or authority figure's involvement in their child's or student's academics is associated with increases in their child's or student's enthusiasm toward education (Henderson and Berla, 1994). However, a parent or authority figure can overplay their responsibilities, thus reaching a critical level that is detrimental to their child's or student's development and long-term fulfillment.

Conclusion

The overall analysis of the interview and observational data displayed mentors playing active roles to create a structured learning environment for their students. The high directive mentor involvement on Team Edison resulted in students conforming to the mentor-led workplace as they completed predetermined outcome tasks and responsibilities. The students were also shielded from failure as mentors ensured a successful robot was built for competition. These findings diverge from the central characteristics of traditional and cognitive apprenticeship learning theories: that learning can occur through modeling and explaining best practices,

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scaffolding to the learner's ability, and transferring the locus of control to the learner (Dennen & Burner, 2008).

The findings clearly show a truncated apprenticeship model as mentors did not fully progress through either traditional or cognitive apprenticeship learning pathways with their students. There was a strong presence of mentors modeling tasks for students, occasionally enfolding them into working directly on the robot while providing context behind their decisions and scaffolding to ensure the student's success. The short-term benefits of the mentors' actions resulted in students acquiring basic skills, the robot working properly, and students seeing success and being inspired to pursue a career in a STEM field. The long term concerns raised by the mentors' action include questioning the students' sustained ability to work through problems, level of confidence in dealing with complex situations, and long term trajectory toward a STEM career.

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