Proximal and Distal Mentors: Sustaining Making-Expertise in Rural Schools

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Abstract

With the increasing interest of integrating Making into formal settings, like public school classrooms, questions have emerged on how to sustain Making as a practice in these environments. Mentors, who can guide students' development of Making knowledge and skills, are needed in these classrooms to facilitate Making activities. In rural areas, the need for experienced mentors is often exacerbated by distance of experienced Maker-mentors from the classroom. In this research we studied how distance mentoring can help a group of high-school students in a rural school to Make and manufacture learning materials for an elementary school in their community. Grounded in literature from Lave and Wenger's communities of practice and Vygotsky's zone of proximal development, the work presented in this paper investigates how mentorship develops in this classroom, becoming less dependent on researchers for guidance and thus becoming more self-sustaining. We discuss how distance-mentors can better train and sustain expertise in Making classrooms, and how our approach may support this mentorship process by aiming mentors and mentees towards a communal goal.

CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**;

Keywords

Communities of Practice, Zone of Proximal Development, Maker Movement, Micro-Manufacture, Public School, Apprenticeship

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1 Introduction

The social acceleration of the practice colloquially known as "Making", the sharing of the production of artifacts through various technologies [17], has been largely researched since the inaugural Maker Faire in 2006 [24]. There has been strong interest in employing Making in education, especially for STEM learning [17, 22]. Currently, many Making-oriented activities directed towards school-age children tend to be informal, transient, and in short-lived contexts such as clubs and after-school programs [22]. There have been recent attempts to study how public schools can adopt Making-practices into their existing curricula, and while these have been successful at developing student self-efficacy [8, 21], mentors with significant Making-expertise are needed to sustain these programs. Researcher-mentors may provide the needed expertise to facilitate learning practices in a Making classroom [5, 6, 21], but there are not enough researchers to provide support to many classrooms for long periods of time. For Making to be sustainable in the classroom, teachers and students will likely need to learn Making from each other [6]. This work presents research investigating how apprenticeship in the classroom can help to create more sustainable sources of knowledge and expertise in public school Making education [6, 21].

Directing students' Making-practices toward a shared goal (i.e. Wenger's Joint Enterprise [29]) in their local community can allow for more effective apprenticeship between all members inside and outside of the classroom. In addition, serving their tight-knit rural community gives students motivation to focus their Maker-skills to produce meaningful products, and seek feedback from their community, much like a consumer's relation with a FabLab. Recent work has also emphasized a "need to develop effective scaffolding strategies to support the youth in the transition from informal learning to technical employment" [15]. To facilitate Making with a Joint Enterprise in the high school classroom, we adopted a model of Micro-Manufacture (M^2) [21], where students worked together to make science kits to support science lessons in elementary school classes. In the M^2 model, high school students engage in "small scales of production (essentially extending from the Making of one to Making of many) for real-world concerns" [21]. We believe that the use of M^2, which is motivated by solving real-world problems, can train students not only in Making-skills but life-skills (e.g. how to apply Making in real-life through teamwork, leadership, critical thinking, problem solving, and time management). M^2 combines Making, Production Engineering, and Life Skills, and can thus fulfill educational standards for 'Career and Technical Education (CTE)' (e.g., [2]), that aims to prepare students for real-life employment. Overall, the M^2 model provides the Joint Enterprise needed to support the apprenticeship of high-school students, support their ability to mentor each other, and support their ability to produce meaningful products outside of their high school projects.

While prior work has shown this model's success in students' Making and Engineering self-efficacy [8, 21], significant time and effort from a diverse group of researchers was needed to initially train high school students to be self-sufficient at producing specified Making-kits. Our hope is that students and teachers in the high school will develop into a Community of Practice (CoP), as described by Lave and Wenger [7], to mentor each other and become less dependent on the research team for aid in the production and deploying of the Maker-kits. In this paper, we investigate how student and teacher expertise is retained or recovered when over half of the students graduated and left the program in its third year. Through the lens of CoP and Vygotsky's Zone of Proximal Development theories [10, 25, 26], we see how mentor roles develop and how help is delivered in the classroom to sustain this M^2 program and further support students to apply Making in their learning.

2 Relevant Background

Previous work has sought to better understand the social aspects of learning in formal education settings, but more work is needed to better understand how Maker-expertise is sustained in these learning environments. Sheridan et al. [23] studied three child-oriented Makerspaces, finding that experienced members guided and motivated newer members to take risks and try new creative activities. Newer members in this study generated ideas for individual Making projects by discussing and observing others' experiences. Similarly, informal Makerspaces help facilitate collaborative learning by providing a common area that serves as a medium for the sharing and combining of products and processes [9]. Naghshbandi further argues that peers in these spaces not only encourage creativity, but encourage teamwork and empathy within the community [20]. Bar-El and Zuckerman's work on Maketec leveraged teen mentors to facilitate the learning of Making-skills among young students [4]. They argued that mentors are an important part of 'unstructured learning' that takes place in Makerspaces, noting that one visitor "expressed his desire to observe the mentors work on projects, and to serve as the mentor's apprentice". Easley et al. emphasized 3D printing for production can help train students about not only Making skills, but prepare them with the communication, coordination, and collaborative skills necessary to be successful at applying Making skills to real-world employment [15].

Previous work by Okundaye et al. demonstrates how high school students can learn and develop self-efficacy around Making-skills via a novel model of Micro-Manufacture (M^2) [21]. This model extends from formal definitions of Making, such as Halverson and Sheridan's definition of engaging "in the creative production of artifacts in their daily lives and who find physical and digital forums to share their processes and products with others" [17]. We utilize that definition of Making throughout this paper. M^2 augments Making practices with production or manufacture at small scales for real-world problems. Okundaye et al. demonstrated that this model developed high school students' self-efficacy toward Making-skills and STEM careers. While they observed "strong signs of the development of a community of practice with recognition of each others skills and preferences", they do not explicitly express which

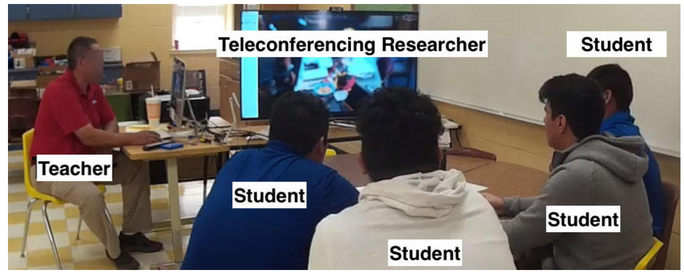

Figure 1: High School Class Teleconferencing with Researcher in Classroom Makerspace (Year 3)

CoP indicators were prevalent, and how student roles served this CoP as a whole. This paper further investigates socially-mediated learning in a M^2 classroom, and discusses how mentorship may facilitate the development and sustaining of Making-expertise.

3 Theoretical Foundation

We observed students through the lens of Lave and Wenger's concepts of situated learning and Communities of Practice [7]. This theoretical framework emphasizes not just the acquiring of knowledge, but the process of becoming a practitioner. Learning is then a process by which one becomes a member of a particular CoP. This framework allows us to better understand how students not only learn Making and Micro-manufacturing processes, but how students may become catalysts of similar processes in the future.

A CoP is centered around a domain, a community, and a practice [7]. Individuals in a CoP interact to build a shared understanding of the relevant practice [13]. CoP exist to advance the practice and social capital of the group, not always focused on the creation of some product [18]. Members support the community through live interactions surrounding the practice, and by recalling stories of the craft [28]. Wenger outlines that every CoP develops through *Mutual Engagement* (negotiation on how a practice is performed), *Joint Enterprise* (the end goal of the practice), and *a Shared Repertoire* (the shared resources of the group) [28]. To judge whether a CoP is developing, we need to observe how these three elements are represented in the practice. The M^2 classroom has a Shared Repertoire through the teacher- and researcher-facilitated resources joined with the classroom resources, and a Joint Enterprise to serve the elementary school students Maker-kits. We discuss about how students develop Mutual Engagement in the Discussion section.

A Strong CoP has frequent exchanges of knowledge among peers, primarily relying on each other for knowledge [11]. In other words, mutual trust within the CoP is needed [3], requiring individuals with experience in the relevant practice. Like a Makerspace, where diverse levels and varieties of expertise are leveraged for the productivity and learning of the group [27], a CoP relies on individuals with varying expertise to maintain and progress the practice. We argue in this paper that placing Making-materials in a classroom is not enough to inculcate students into a CoP, but external knowledge sources are needed to start the a makerspace-esque learning practice. To further investigate how knowledge is shared within a potential CoP, we employ the theoretical lens appropriated from Vygotsky's social development theory and the zone of proximal development (ZPD) [10, 25, 26]. Vygotsky emphasizes that learning processes depend on social interactions. Students learn the social

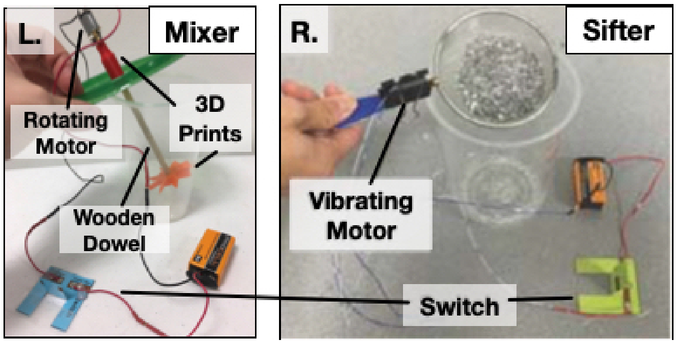

Figure 2: Maker-kit for 'Mixtures and Solutions' topic

constructs of knowledge and meaning through people with various levels of knowledge [12]. The ZPD of an individual is the level of knowledge where a student may be able to work with the help of a 'More Knowledgeable Other' (MKO) [12]. In our study, MKOs were frequently instructors and teachers [19], and occasionally were student peers [1]. While CoP approaches learning from a phenomenological perspective, focusing on levels and attributes of participation, Vygotsky's theories provide a lens into how student roles result in a learning dynamic between individuals.

To infer whether our observations of socially-mediated learning in the classroom are indicative of Makerspace-esque learning, we employ a framework of Makerspace Learning Practices defined by Wardrip and Brahms [27]. They explained that Makerspaces may facilitate learning through the Learning Practices of *Inquiry* (curiosity-driven exploration and questioning), *Tinker* (purposeful play, testing, risk-taking, and evaluation of materials, tools, and processes), *Seek and Share Resources* (identification, pursuit, and sharing of expertise with others), *Hack & Repurpose* (harnessing and salvaging of materials, tools, and processes to modify, enhance or create a new product or process), *Express Intention* (discovery, evolution, and refinement of personal identity through determination of short and long-term goals), *Develop Fluency* (development of comfort and competence with diverse tools, materials, and processes), and *Simplify to Complexify* (demonstrating understanding by connecting and combining components to make new meaning). Indicators of these Learning Practices can help us test for the existence of unstructured learning, and how learning is facilitated, within informal Making settings. In this paper, we investigate how the M^2 classroom may exhibit these Learning Practices. [27].

4 Methodology

This paper analyzes data from an ongoing study, presently in its third year. This study has been conducted in collaboration with a rural school district along the Texas-Mexico border. The school district is around 43 miles (around 51 mins driving distance) from the nearest larger town. Six students, in their 2^{nd} or 3^{rd} year of high-school, were recruited to participate in the first two years of the study. Looking for students with diverse interests and capabilities, we received 13 applications. We interviewed those 13 via teleconferencing, and selected six students with a diverse set of interests, backgrounds, and career goals. Two more students were recruited to participate after the 2^{nd} year.

4.1 Elementary School Science Making Kits

The end product from students in this M^2 program was to create and deploy science instructional kits to aid in 5^{th} grade elementary school science lessons. These Making-kits were designed to align with and augment specific science topic learning standards taken from state-mandated curriculum. The elementary school class they served consisted of 15 students, with most students working in pairs using the Making-kits. As technology in the hands of elementary students showed to be prone to breakages, the high school students were instructed to produce at least 10 kits for each science lesson.

All designs and details about the kits were developed by the research team, and then delivered to the high school students. The kits combined arts and crafts with Making, aiming to be usable by children as young as 8 years old. For example, one unit aimed to teach students the difference between mixtures and solutions, having them assemble a mixer and a sifter (shown in Figure 2) to experiment with the combination and separation of different materials (e.g gravel, metal clips, toothpicks, water, salt, etc.). The mixer consisted of a geared rotating motor that drove a 3D printed mixer head via a quarter-inch wooden dowel rod. The sifter consisted of a vibrating motor attached to a small sieve. Students would connect these two devices to a custom-made paper-based switch and a 9V battery. High school students were encouraged to modify and add to the kits, with approval from the research team. For example, students could not find a good local supplier of the 0.25" dowel rods, so they utilized pencils to accomplish to same task.

4.2 Study Description

This longitudinal study has been ongoing for over 3 years. The entirety of the first year was dedicated to training the classroom to learn Making and M^2 skills for the purpose of deploying Making-kits. Years two and three involved high school students manufacturing and deploying their kits in the elementary school classroom. Between the second and third year, two students graduated and two students left because of class scheduling conflicts and testing-preparations, leading them to be replaced by two new students by similar recruitment. The first and second years had three female and three male students of the same seniority in the program, while the third year consisted of four male students where half are new and the remaining have two years of experience in the program.

As local high school teachers are not fully familiar with the skills and instruction needed for Micro-Manufacture, the classroom was taught via a distance apprenticeship approach by the research team that consisted of experienced members in Making, computer science, engineering, industrial distribution, educational technology, and interaction design. In this paper, we refer to those who teach apprentices as "mentors", and those who conduct distance-apprenticeship as "distance-mentors". Over teleconferencing calls, these researcher-instructors would teach about various Making skills (soldering, connecting basic electronics, programming, 3D printing, etc.) and M^2 skills (supply chain, inventory management, batch processing, production line, etc.).

Year 1 was dedicated to training the high school class, students and teachers, to produce and deploy Making-kits. To help encourage interactions like in a Makerspace, we augmented a high school classroom with the needed equipment and layout to resemble a

Makerspace. Equipment such as hand-tools, electronic components, and a 3D printer was provided. Students were given the freedom and responsibility to organize themselves and the equipment in the classroom. The initial team of six high school students were taught Making and manufacturing skills by the research team. To facilitate this distance apprenticeship approach, a large television and teleconferencing web-camera was installed in the classroom.

To help start initial communication, students starting the program in this first year attended an in-person workshop at the researchers' laboratory. Here, Micro-Manufacture was explained to the students as consisting of: i) understanding and deconstructing a given kit design and specifications; ii) adapting kit design to local conditions; iii) producing one kit; iv) planning the manufacturing process; v) engaging in the production pipeline; vi) quality testing; vii) deploying kits in the classroom; viii) conducting a post-assessment of the deployed kits. After this workshop, where they saw example Making-kits and were guided in an abbreviated process to manufacture these kits, they were tasked with creating many sample kits as a Making-Production Team(MPT) in their classroom. These sample kits were their objective for the rest of year one, where a teleconferencing researcher would aid them in this process. Each class started with a recap of the previous class, and a review for what needed to be done in the planned manufacturing process to produce the sample kits. The teleconferencing instructor would give students high-level tasks if the prior-assigned tasks were completed. Finally, students would complete these tasks. During the classes, student would learn by participating in this shared practice with the teleconferencing researchers. This first year started in the second semester, covering 18 weeks and 6 sample science kits that varied in Making materials and Manufacturing processes. This year largely served as an introductory lessons and practice kits to train the groups' making and micro-manufacturing abilities.

Year 2 for the MPT consisted of them applying the knowledge they gained producing sample kits to actually manufacture and deploy kits in the real elementary school. This year covered both semesters, totaling to 36 weeks. The MPT were given the target to manufacture 10 kits and deploy them every six weeks, corresponding to the cycle where the elementary school science classroom covered a given curriculum theme in the Texas school year. In addition, students were assigned formal roles to aid in their Making and Manufacturing process: 'Project Manager', 'Production Manager', 'Sourcing Manager', 'Administrator', 'Continuous Improvement Specialist', and 'External Relations Manager'. These roles were developed to give more structure to how the community received input (e.g. Sourcing Manager purchasing materials), processed information (e.g. Production Manager on developing a pipeline for the manufacturing process), and developed output (e.g External Relations Manager). The high school students traveled to the elementary school on the day of deployment (i.e. the science lesson), helping the 5th grade students interact with the Making-kits.

Year 3, still in progress at the writing of this paper, consists of similar tasks to Year 2. However, there are three notable differences. One, two students in the program have graduated, leading to them being replaced via a recruitment process similar to Year 1. Two, the two retained students (RS) in the program are now experienced in the actual manufacturing and deployment process for the elementary school. Lastly, the first six-week unit of this year is a practice unit with no real deployment. This will give the MPT, with new members and social dynamics, an introductory period to establish their practice before making and deploying elementary school Making-kits for the remainder of the school year. This paper focuses on the 3rd school year's first 8-weeks, the first practice unit plus two weeks, comparing how the mentor-roles and knowledge-needed in the classroom differs from the first two years of the program.

5 Data Analysis

In this paper we analyzed recordings of several classroom sessions to investigate the following research questions: **1)** Are Learning Practices similar to that of a Makerspace taking place in the M^2 classroom? **2)** How do Experienced Students and Teachers retain and utilize expertise gained from previous years in the program to mentor less-experienced members? **3)** How can a distance-mentor effectively train members in a Maker-program that sustains expertise similar to a Makerspace CoP?

To approach these research questions, we analyzed a sample of classroom sessions over the last three school-years of the program. Each class session, averaging about 40 minutes, was captured with two strategically placed video and two high-quality audio recordings. Figure 1 shows one camera view with all of the 3rd year classroom members. The audio recordings were captured using production-quality field recorders, and these recordings were remastered onto video streams to ensure audibility for coding. A team of seven coders analyzed data from 8 sessions for year 1, 24 sessions for year 2, and 25 sessions for year 3. For each session a coder wrote memos describing the process of each class, noting in detail events related to the lenses of ZPD and CoP.

The team then engaged in a deductive qualitative analysis approach [16]. The deductive approach relies on the development of a 'categorization matrix', derived from prior research or theory. This matrix serves as a framework to categorize aspects of the qualitative data. Aspects that did not fit in this matrix were also noted based on principles on inductive analysis. We made use of a categorization matrix related to Lave and Wenger's theories (e.g. open dialog, levels of participation, etc.), ZPD from Vygotsky (e.g. More Knowledgeable Other, Scaffolding, etc.), and Learning Practices proposed by Wardrip and Brahms (e.g. Tinker, Inquire, Repurpose, etc.). Following these theories, our analysis focused on how learning was facilitated through social actions. For a random sample of 25 of 34 total days of recordings in year 3, coders identified every instance of help given or received in the classroom.

Following Wardrip and Brahm's Makerspace Learning Practices, we highlight instances of social learning as facilitated by the different classroom agents. These practices serve as a scheme to observe and evaluate instances of learning in our classroom, verifying that it operates similarly to a Makerspace, and gives us a framework to further analyze how Learning Practices are supported through its members. Our coders focused on instances where any individual gave help to other individuals in the classroom. More categories were added to the categorization matrix as new significant aspects emerged in the coding process. Coders noted who gave help to which others, whether the help was asked for by a student, whether the help was needed or successful, if the help was related to their

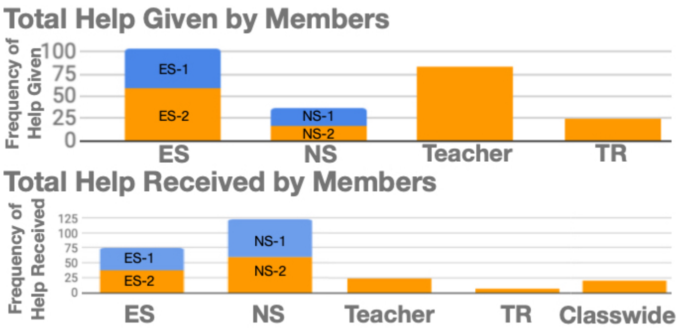

Figure 3: Instances of Help Given and Received in Classroom

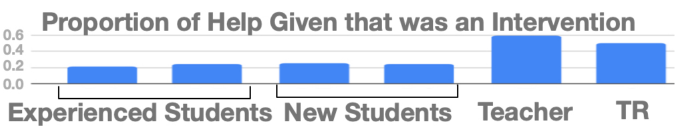

Figure 4: Proportion of Help Instances Given as Intervention

shared project, and whether the help was announced to the class or aimed towards individuals. Each instance of help was described by a brief summary of what help was given and for which reasons. Coders then met to review these instances of help, and identified common themes. One of the coders met with all of the other coders to discuss and resolve codes and themes in all observations.

In year 1 of the program, researchers served the functions as ‘masters’, using Lave and Wenger’s term, and the students and teachers as ‘apprentices’ to be inducted into the M^2 practice. In year 2, the team moved into a production mode where they became directly engaged in the M^2 practice. There was significant turnover in students in year 3, with four students leaving the program (two seniors through graduation and two rising seniors who decided that they needed to focus on their upcoming SATs), and two new juniors were added to the team. This affords us the opportunity to observe the evolving roles of the participants by analyzing the dynamics of how help is given and received.

6 Study Findings

The goals of this study was to understand how CoP may manifest itself within the M^2 high-school program, and how unstructured learning may be scaffolded by social interactions between peer and instructor MKO’s. We observed that help given by the Experienced Students (ES) was largely greater than New Students (NS), indicating that they took on mentor roles to help train the new students. First, we present evidence that the observed classroom facilitates learning practices similar to that of a Makerspace (RQ1). Then we explain how the group addresses gaps in knowledge between years, conveying knowledge retained in the classroom (RQ2), and how effectively the Teleconferencing Researcher (TR) could fill these gaps and further facilitate the retention of this expertise (RQ3). Finally, we present our observations that indicate the development and assumption of roles in the classroom. These roles indicate how mentorship may take place in the classroom (RQ2), and how effectively distance-mentors may be at providing mentorship compared to the classroom-proximal members (RQ3).

6.1 Learning Practices

Based on analysis of a museum family Makerspace, Wardrip and Brahms [27] identified seven socio-cultural processes that support learning in Making. Our analysis found instances of each process, but facilitated by different members in the community-classroom: ES, NS, TR, and the Teacher.

Tinkering took place solely by students, often experimenting with how new circuits connect and learning about near materials and properties. The students were also the sole individuals to *Hack and Repurpose*, although only ES were observed doing this. For example, since wooden dowel rods were difficult to obtain in the rural setting of their school, one student proposed the repurposing of wooden pencils to perform the same function in their Maker-kit. Students familiar with 3D printing would occasionally modify designs to fit school needs, such as modifying a part that attaches to markers to match markers they had on site. Also, students would often create and participate in Making processes of their own choosing, as discussed further in the section 6.3. Students occasionally *Inquired* about how their Making-kits and acquired skills could be applied to make familiar technologies. In the second year, one student briefly asked about and researched how to make a portable USB battery charger. These instances signify that students may seek to apply their Making knowledge and skills in the future.

All members participated in the practice of *Seeking and Sharing Resources*, which required them to identify, pursue and/or recruit expertise of another to complete a given activity. Figure 3 illustrates the total number of help instances given and received by different members in the classroom in our Year 3 analysis. Students gave the majority of help received by their peers. The Teacher gave comparable amount of help to the ES, and the TR gave comparable help in comparison to the NS. However, the TR was only present on about three out of five days of the school week. In the third year, over three-fourths of the help that was given by each of the students was sought by other students, and the majority of help received by each member was sought as well. The Teacher would often ask students about their current tasks, which served to create a more Open Dialogue about what all members were completing, so that students could share their expertise to work better as a whole to complete their Making-kits. The TR would often facilitate the students’ seeking of help from each other, by delegating students to work together and by employing Socratic Method during longer lectures. In a lesson covering the use of breadboards in prototyping circuits, the TR asked “Ok - Let me just - let’s start out with the seniors for our group. Based on what you know, what can you tell me about breadboards?”, “What exactly is a breadboard?”, “What is it used for?”, etc. In another early lesson in the third year, the TR would encourage the NS to seek help from the ES, saying “<ES-1>, I’ll have you kind of watch over <NS-1>, but for detail but <NS-1> I want you to primarily do it by yourself.” By encouraging cooperation, discussion, and establishing the ES as sources of knowledge as part of the lessons, the TR further facilitated the Seeking and Sharing of classroom resources. In the second year, we saw less instances of the TR employing these methods, and less TR help related to Making skills requested from students, indicating that students who have established Shared Expertise in their community do not require as much help from the TR. A community that can effectively seek and share resources encourages learning and sustainability of the groups shared expertise.

New students would often *Develop Fluency* by asking their peers how to complete tasks and learn the needed language to communicate about these tasks. For example, when writing daily reports on what they completed that week, the new students asked ES-1 about what they did: "I put – I made switches... Is that ok?", prompting the ES-1 to respond "You soldered switches", which then NS-1 repeated that phrase while writing. Similarly, both the TR and Teacher would serve as the mentor to develop fluency in certain cases where students either were not confident in helping each other. While the teacher was able to function similarly to the ES in the classroom in the Development of Fluency, the TR often ran into challenges communicating more complex Making-processes and concepts. To overcome this gap, a common strategy was to encourage students to *Simplify to Complexify*. In this process, students were encouraged to start with simple representations of a more complex subject, and then connecting and combining simpler component elements to make new meaning. One such instance happened where the TR assigned the two NS to work together on a circuit. They met a challenge during this task, leading them to ask an ES for help. The ES was unable to help, resulting in the students showing the TR the problem circuit on the web camera. The TR suggested breaking up the more complex parallel circuit into a single circuit, then expanding it after that simple circuit was constructed properly. The students were able to succeed at this task with this guidance, and without further explanation of the circuit itself. The Teacher also encouraged this simplification process at times, particularly asking students to test smaller components when larger constructions were not functioning properly.

In this 3rd year, the students and teachers were solely responsible for how the students' *Express Intention*, the discovery and development of identity and interests areas through determination of short and long term goals. The teacher served as a reminder for long-term goals, reminding students throughout many of the classes about qualities of the elementary school. He would make sure students guaranteed that "every kit has everything it's supposed to". Students would often assign short terms goals for each other, with the seniors often leading the execution of those goals.

In this classroom, with varying student levels of expertise, Wardrip and Brahm's Learning Practices are largely supported by students. The TR and the Teacher serve primarily to introduce new concepts and intervene when needed. NS often do not have the needed experience to serve as a 'more knowledgable other' (see Figure 3), so other students often fill in knowledge when able. The Teacher serves as a proximal resource, intervening when students may lose sight of long-term goals and quality control of their products. The TR serves to address gaps in knowledge, encouraging students to leverage each other's expertise, while injecting strategies of problem-solving and Making, such as *Simplify to Complexify*. Through this process, we see how the dynamics of Vygotsky's social development theory result in the propagation of knowledge in this classroom CoP.

6.2 Addressing Gaps in Knowledge

In a CoP, members are expected to have varying levels of expertise that they employ to drive their practice. The loss of multiple members may cause enough of a gap in knowledge to suspend the

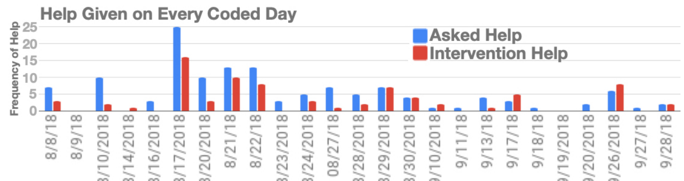

Figure 5: Help Given over Time (249 Total Coded Instances)

practice of the group. With the exit of four students at the end of the second year, the class in the third year had to account for any knowledge that may have solely belonged to those members. In one instance, the class discussed the loss of the person who usually performed the breadboard prototyping, with ES-2 saying "He was the only one who knew how to do it". ES-1 then chimed in "Well, I know how to do it, but I forgot. Well, I didn't forget, I just...", prompting NS-1 to say "You didn't forget?". ES-1 responded "Más o menos (English: more or less)". The Teacher, who had participated in prototyping and testing circuits with the breadboard in past years, then intervened and helped guide the students. In other cases, students attempted to help each other while heat shrinking wires and students were learning how to use box cutters, but the Teacher intervened to make sure proper protocol was followed.

Generally less help was given as time progressed in the third year (see Figure 5). Most days saw more help asked for than not, although about half the days saw a close balance with intervention-based help. Help was largely received by the NS, while all students received intervention help a little under half of the total instances (see Figure 4). These observations indicate that both intervention and self-driven knowledge seeking both play a crucial role in this Making classroom. To facilitate a successful Making CoP, experienced members must be present to intervene with students' Making-processes, aiding the development of Making-fluency.

6.3 Development of Roles

For a CoP to develop and sustain, members with greater expertise (i.e. MKO's) are needed to take on central roles that facilitate Legitimate Peripheral Participation. Members with less experience learn through observing and engaging incrementally in more central roles on the team. This Legitimate Peripheral Participation was observed in several instances in the third year of this project. That took place often through students' evaluating each others' work (e.g. "Oh my God... you're going to have to desolder it"), or by observing others (e.g. watching ES construct a flow chart). Over time, members' ability to engage and mentor different skills and processes led students to develop roles in the classroom CoP.

Between the NS, even in the relatively short time we observed them, one of them developed a keen interest in the design and assembling of circuits for the Maker-kits (NS-1). When NS-2 poked fun at his football ability, he joked back "I can make better switches than you". This difference in ability did effect the self-efficacy of NS-2, who said "I will pretend I can build" after the other student made a circuit. We observed this also effected students' eagerness to participate in circuit-building proportionately, which may continue to affect the students' self-efficacy and ability into the future.

The ES had existing roles before the third year, where both frequently: worked with the 3D printer, helped assemble circuits, and helped plan the elementary school lessons and kits. In this new year, one assumed more of a leadership role. In one instance, NS-2 was working at a table, and the Teacher came to ask what that student was doing, saying that each kit needs a battery for each light. ES-2 quickly jumped in, saying "he's just making sure all the LED's work". The Teacher left, and NS-2 signaled thanks to ES-2. Later when the teacher briefly left the classroom, ES-2 spread out his arms horizontally and said "I've got leadership qualities" a few times while pacing back and forth next to the new student. ES-1, at a later date when he was alone with the two NS, mockingly mimicked the absent ES-2: "You did this all wrong. You're not supposed to do it like that... I bet anything he is going to say that". This particular interaction reflects interactions in year two, where all students had the same seniority and were not afraid to criticize each other.

A hierarchy of authority emerged as this community evolved. Throughout the program, the TR was granted supreme delegation ability by all members, likely resulting from being the initial source of knowledge. The Teacher often would coordinate and follow instructions from the TR, while ensuring all students were engaged. However, the ES would sometimes disregard the Teacher's delegations. ES often would negotiate tasks amongst themselves, but more assertively delegate to the NS. The NS sometimes attempted at delegating roles. For example, the circuit-minded NS-1 once tried to recruit NS-2 to help solder. ES-1 overrode that delegation, saying "he is helping me with this [emailing]". This hierarchy also often applied to the order in which help was given. In one particular case, the TR assigned circuitry tasks to the NS. When one NS failed, their peer helped them, then a ES, then the Teacher, and finally the TR. The supreme and final authority of the TR is not always beneficial, as in one case where he tasked the students with completing status reports. This interrupted their tasks, and when the Teacher asked why they were doing the reports so early, the students replied variations of "He [the TR] told us to". However, as time progressed the TR gave less and less help to the students (see Figure 5). Coders explicitly noted that in later classes, the TR conversed very little. As the TR rarely participated after the first three weeks we observed in the third year, the TR did not interfere or interrupt the flow of the classroom in a similar manner. The Teacher was more successful at negotiating tasks and roles with the students, where the TR was a more external influence to the CoP. Lave and Wenger state that members in a CoP must join with experience in the shared practice, so the TR helps introduce students with initial experiences. After these experiences have been introduced, the TR's relative mentorship effectiveness appears to be less than those in the classroom. From our above observations, we believe that self-sustaining Making expertise through socially-mediated learning in a CoP can be initiated via teleconferencing MKO's experienced in Making.

7 Discussion

In this study we identified instances of Wardrip and Brahms Learning Practices, indicating learning similar to Makerspaces is taking place within the M^2 classroom. Further, we analyzed many socially-mediated learning instances to show that expertise was not only retained by the experienced students, but that they largely contributed to the mentorship of new students. In this paper we found evidence that these rural Makerspace classrooms, faciliatated in part from distance apprenticeship, have the potential to sustain expertise and drive the further development of Maker-based education in public schools. Through the existence of Wardrip and Brahm's Makerspace Learning Practices, we can confidently state that students in the observed classroom learned similarly to a Makerspace (RQ1). We measured that students retained and utilized expertise throughout the program, needing and asking for less help as they gained experience (RQ2). We observed that the distance-mentor (i.e. the TR) effectively introduced students to Making concepts via lectures, intervened with mixed results, but was needed less over time as the classroom-proximal members developed skills and mentorship abilities (RQ3). In this section we discuss how rural classroom CoP's may facilitate Making via distance apprenticeship, and how what intervention strategies can be taken to better drive CoP developement and sustained expertise in these classrooms.

7.1 Classroom Community of Practice

One challenge to implementing Maker-based education in rural schools is the need for experienced practitioners to mentor students in the program in Making knowledge and skills. Over time, individuals develop roles and practices based on self-guided projects and may form a CoP to sustain expertise to complete these projects. In order for Making-based rural public school programs to succeed, we must further investigate how to facilitate CoP-development within Makerspace classrooms. One challenge is that there may not be many readily-available proximal mentors to help start these classrooms on their practice. In this paper, we discuss how our distal mentors may facilitate the development of a Making-CoP and the sustaining of a expertise of the classroom across multiple years.

As students would often be forgetful of the long-term goals of making and deploying Maker-kits (i.e. the Joint Enterprise), the Teacher consistently acted to remind students to work towards these goals, assuring students had tasks that aligned with those goals and that their products fulfilled their plans. This Joint Enterprise gave the classroom a clear objective to develop expertise needed for a CoP. The Teacher and TR drove students to develop a Shared Repertoire, encouraging them to facilitate each others' learning whenever possible. The students' learning, situated and facilitated in their Makerspace, Developed Fluency on how and why to utilize Making tools and processes. This further encouraged the development and sustaining of a Shared Repertoire, facilitating the transfer of knowledge surrounding the Making-practice by connecting expertise with proximal tools and processes.

The classroom showed signs of Mutual Engagement, a negotiation of how the the construction and deployment of Maker-kits was completed, through the roles they converged upon. More experienced members took a more central role in defining and acting in the process, like Wenger's theories on 'masters' of a CoP [7], and had more control on how the practice evolved. The authority hierarchy (Section 6.3) conveyed how this Mutual Engagement developed. To maintain this Mutual Engagement, it is essential to facilitate and conduct effective interventions in the classroom.

7.2 Making-Intervention in Rural Schools

While interventions are essential to continuing the practice and sustaining expertise in the Makerspace CoP, rural schools have the additional challenge of being distal to many educational resources that are more readily available in urban areas [14]. To combat this, we employed a distance apprenticeship approach where we teleconferenced via a classroom television to instruct the classroom making practice. We observed that the TR and Teacher noticeably intervened more in the classroom, addressing perceived gaps in knowledge and reminding students of their goals. While students (particularly ES) gave more help overall compared to the Teacher and TR combined, they intervened relatively infrequently.

For expertise to be inculcated in the Making classroom, intervention is needed from MKO's. The TR in our study served as this external knowledge source, and consequently often had supreme authority in the classroom which was good for injecting knowledge into the group but also had the potential to interrupt the flow of the students' Making practices in the classroom. The TR spoke very little during many later classes as to not interrupt the classroom. To combat this, we propose two potential approaches to sustain expertise in these Making programs. One is to comprehensively train or recruit teachers with Making expertise, which would likely be the most effective at mentoring due to their knowledge of students and the school, but this can be difficult in rural areas where schools and teachers are more sparse. The other approach is to utilize teleconferencing technologies for the classroom so distal individuals may be situated in the classroom more similar to a teacher. This could allow for a distance-mentor to more effectively diagnose student issues, like improperly wired circuits, and intervene before the student may ask for help. More research into how Making can be taught from a distance may give insight into how distal mentors can train many rural school students and teachers with the needed expertise to sustain their own *M2* programs. Overall, peer mentorship appears sufficient to facilitate requested help, but not intervention-based help. Teachers, possibly with support from distance-mentors, are needed to sustain expertise amongst the students via intervention.

7.3 Study Limitations

The study was limited to the specific setting and the number of participants engaged in the study, and may not be generalizable to all high schools. In particular, the absence of female students in the third year may have changed the social dynamic of the classroom from previous years. Insights from this study, and continuations of this ongoing study, may further inform approaches to scaling and sustaining Making-based education in rural public schools.

8 Conclusion

In this paper, we investigated means of initiating and sustaining Making-expertise in rural high classrooms via a distance apprenticeship approach. We discovered that it is possible to maintain Makerspace Learning Practices, while also fostering a Community of Practice where peers acted as mentors for each other. Students received significantly less help as time progressed in our analyzed eight-week window, suggesting that students became increasingly proficient in their ability to serve their community through Making. In these eight weeks, the 3rd year students provided more help than the Teacher or the Teleconferencing Researchers. However, Teachers and Teleconferencing Researchers provided the majority of intervention-based help. To properly address gaps in knowledge through interventions, our results suggest that classrooms need teachers or distal mentors. While teachers provide the most effective intervention-based help in the classroom, we hypothesize that future research and technologies could improve the intervention abilities of distal mentors. We project that similar high school distance-apprenticeship programs, aimed towards a predefined goal, can help students solve local social and environmental challenges, all while training students to be proficient in Making life skills.

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