The Double Bind of Constructionism: A Case Study on the Barriers for Constructionist Learning in Pre-college Engineering Education

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Introduction

In the United States, constructionist learning theory (i.e. *constructionism*) has been one of the dominant paradigms underpinning pre-college engineering education both out-of-school and in-school. Historically grounded in mathematician Seymour Papert's research with the educational programming language Logo, constructionism builds on and distinguishes itself from Piagetian *constructivism* [1]. It assumes that young people learn new information by actively reconstructing it within their existing knowledge frameworks but adds that this is best done when making and doing things. This material learning through design lends itself to the focus on constructing, building, and making that is encouraged in pre-college engineering education [2],[3]. In school, constructionism has supported teachers' implementation of sandbox software (e.g. Scratch) and modular hardware (e.g. LEGO) to move engineering design across curricula, including science, technology and math [2],[4]. In after-school or out-of-school contexts, constructionism underpins engineering education programs like the FIRST Lego League—which uses the constructionist technology LEGO Mindstorms, named after Papert's 1980 book, *Mindstorms: Children, Computers, and Powerful Idea*s [5].

Whether in school or out-of-school, constructionism has been framed as a means to breakdown traditional teaching/learning hierarchies, reconstituting education as student-centered, design-based, and hands-on. The common positioning of the teacher or adult by constructionism is that of the facilitator or coach who provides young people with resources and a context for creative and self-directed exploration but does not lead, lecture, or insist on predetermined outcomes. It has long been recognized that the constructionist positioning of the teacher, along with the legacy of Papert's anti-school attitudes [6], creates tensions and difficulties when pushed up against the standardized and top-down structure of traditional schooling [7]. Considering this history, how does the constructionist positioning of the teacher play out in 21st century pre-college engineering education?

This paper uses a descriptive single-case study research design [8] to analyze qualitative data on one Upstate New York middle school technology teacher (pseudonym Julie) who embodied constructionism by, in part, using constructionist technologies to expose students to engineering design. From the larger case of Julie's teaching and coaching, we detail three sub-cases: one to highlight Julie's constructionist practices and two to highlight the barriers faced by those committed to constructionist learning. Triangulating these three sub-cases reveals how the constructionist positioning of the teacher can create a pedagogic "double bind" [9], where self-directed and hands-on learning with constructionist educational technologies is simultaneously positioned as an advantage for student learning and development but also as an immediate disadvantage to their achievement in the larger educational structures in- and out of Julie's school.

Literature Review

Constructionist Learning Theory

To understand how constructionism is situated within U.S. pre-college engineering education, it is important to begin with its theoretical foundation and socio-technical history. This helps us to frame constructionism as both a learning theory and educational strategy [10]. Theoretically, it begins with Papert's relationship to Swiss developmental psychologist Jean Piaget in the 1950s and 1960s. Inspired by and grounded in Piaget's constructivism, constructionism regards learning as "building knowledge structures" by accommodating and assimilating information [11],[12]. However, constructionism's take on learning and development is not so much descriptive as it is normative, making contextual considerations such as learning preferences, engagement, and aspects of "style" that are often alternatives to formalized expressions of knowledge [13]. This shifts learning and development from universal *stages* to radically plural and individualized *styles* [14], [13]. Even more distinct from constructivism, Papert argues that learning is best when young people are engaged in building physical and computational artifacts that support the discovery of ideas, knowledge, and relationships. Indeed, Papert [12], [1] positions computers as "objects-to-think-with," which help young people construct and reconstruct knowledge and the material world around them by flattening the traditional concrete and abstract epistemic hierarchy.

Constructionism is exemplified with the educational programming language, Logo. As Bers [28] explained rather informally, "Seymour understood the importance of 'objects to think with'. These objects can help us make ideas concrete, tangible and sharable. They also empower us to have new ideas or to see old ideas in new ways. Objects can exist on the digital screen or on the physical world. Seymour knew about this early on. The Logo turtle was both a virtual cursor and a floor-based robot." Indeed, Logo was designed to challenge Piaget's idea that formal or scientific thinking is separate from concrete thinking [12]. When using transitional objects either on computer screens or as robots, concepts once thought of as only accessible for children at the formal stage, such as recursion, were said to become understandable by children in the concrete stage [12]. Rather than getting ideas from their interactions with the program, students use Logo as a means to experience the abstract as concrete in the design of personally meaningful artifacts that are grounded in their existing experiences, desires, and interests [12], [1], [15]. These artifacts can be games, drawings, poems, or other creations that support discovery learning. This desire for immersive learning based on physical and/or digital manipulatives was a direct challenge to the "skill and drill" educational technologies of the time, such as those based in the computer aided instruction model [16].

Constructionist Positioning of Teachers

The commercialization of Logo and subsequent boom in the availability of personal computers in the early 1980s, led to the rapid adoption of Logo across the U.S. [7]. Logo was expected to reach hundreds of classrooms and impact the way that thousands of children learn and think. Among early proponents, contrasting camps formed around the degree to which Logo would change education [7], [17]. On the one hand, some of Logo's creators envisioned its incremental role in reforming education, while, on the other hand, some creators, including Papert, thought it had revolutionary potential to shift education from teacher-centered, instructionist pedagogy to student-centered, constructionist learning. It has long been noted that constructionist theories and technologies disrupt the traditional teacher-student hierarchy, particularly in school settings. In Papert's radical efforts to revolutionize education, the role of teachers shifts from one who transmits knowledge to that of the facilitator who provides a context for self-discovery. As facilitators, teachers deepen student knowledge through: a) framing how a specific set of behaviors leads to problem solving and b) bridging how certain processes look across contexts and disciplines [18]. However, the empirical work on Logo calls into question the possibility of enacting either camps' goals.

In spite of the rapid acceptance of the constructionist technology by educators and parents, early critiques of Logo stem from the lack of conclusive empirical results to support traditional school expectations [19], [20], [21]. This made Logo's place in traditional schooling somewhat contentious and made the revolutionaries double down on their convictions, arguing that Logo worked but that the institutions were often too obdurate to implement it successfully. Tensions grew to the point where some researchers and scholars called on a moratorium of the programming language until more research was conducted to determine its appropriateness for the classroom [19]. Given these tensions, constructionist technologies found more comfort and flexibility in after-school and out-of-school contexts.

Constructionism Out-of-school

While variations of Logo continued to be used in schools, out-of-school programs, such as the Computer Clubhouse and FIRST Lego League, have become more popular venues for constructionist technologies since the late 90s and early 2000s. These contexts became foci for shaping and exploring constructionist learning for a new generation of young people. In after-school and out-of-school settings, educational robotics became uniquely supportive for applying constructionism to engineering design education [22]. Similar to the early promotion of Logo, the hands-on engineering design affordances of educational robotics is purported to advance students' knowledge and skills by flattening the hierarchy between concrete and formal thinking [23], [24], [25], [15].

As children engage in robotics activities they are given the opportunity to learn-by-doing, a foundation to constructionist design that reflects real world enterprises and encourages the material exploration of "big ideas" [26], [12], [2], [27]. Robotics kits for out-of-school contexts are increasingly framed as objects-to-think-with, bringing together computer programming and the design of computational artifacts. Still, as we will explore below, it is important to point out that today teachers also find constructionist technologies useful in their classrooms. But, the positioning of the teachers as facilitator has not changed much since the early days of Logo. For example, in one guide for using the constructionist robotics kit LEGO Mindstorms, teachers are encouraged to not worry about the extent of their engineering design or computer programming knowledge when implementing the technology in-, after-, or out-of-school [22].

Context and Methods

As described above, constructionist learning theory and constructionist technologies like Logo do not always align well with the goals and structure of traditional schooling. While PK12 engineering education is not as standardized as mathematics, English Language Arts, or even science, once it is fit within school structure it runs up against many of the same barriers. For example, in this paper we explore how such tensions played out for one middle school teacher, Julie, across one academic year (2014-2015) as she sought to use the proprietary constructionist educational technology LEGO Mindstorms to support engineering design education in and out of her classroom. As we will see, the tensions between constructionism and traditional school structure continue in the 21st century but have the added stress of high-stakes testing regimes and district moves toward curriculum standardization. In addition, we also show how the obstacles and barriers for teachers who are committed to constructionism, such as Julie, may not be confined to in-school but, contrary to much of the celebratory literature on constructionism, also present themselves in out-of-school contexts, albeit in different ways. Before detailing our descriptive single-case study methodology and outlining our findings, we provide some background on Julie, her school, and her relationships to constructionist technologies.

Teacher and School

Julie is a White middle age woman who, as of 2018, was a National Board Certified teacher, a NYS STEM Master Teacher, and had been teaching in the same large urban New York State school district for approximately 27 years. The school where she works serves predominantly Black and low socio-economic status communities. According to New York State enrollment data, for the academic year that data for this paper were collected (2014-2015), over 50% of students at Julie's school were identified as "Black or African American," with the next two largest racial and ethnic groups being "White" and "Hispanic or Latino." In addition, students who were identified as "economically disadvantaged" made up over 50% of the school population.

When Julie first started teaching, her courses were considered Industrial Arts and consisted of activities associated with wood or metal shop. Today, her courses are considered Technology Education, which, by New York State learning standards, is a required unit to be completed between 6th and 8th grade. While her classroom, which is lined with computers from wall to wall, can be confused with a computer class it is distinctly different. As Julie explained, " Technology education is basically the man-made world. Using tools and resources and knowledge to come up with inventions or innovations to meet needs and wants." So while computers are used regularly, they are not the main focus, but instead fitting into a larger ecology of technologies (from 3D printers to woodblocks), which, notably, support engineering education.

While Julie did not always explicitly consider what she was teaching engineering, she later recognized how what she called the "problem solving" parts of her curriculum fit into the category of engineering design. When asked about how engineering design fits into her curriculum she explained:

> First of all… define the problem? What is the problem? We were designing a container to hold an egg. Keeps the eggs safe when we drop it. We set goals. They develop solutions, pick the best solution, tests out the solution, evaluate the solution, and keep going back through the engineering design process. So it's something that's incorporated in sometimes purposeful and sometimes after the fact… It's just always problem-solving or just a different term but it's always been in the curriculum, how people define those steps is different. Like the high school Project Lead the Way, there's twelve steps in the process, [in] middle school I've cut it down to about six steps.

In addition to incorporating engineering design into her technology education curriculum, she also does so in after-school programs. In addition, she participates in technology-based professional development, some of which is run out of a local engineering college.

Julie's approach to engineering education is reminiscent of Papert's [12] intentions with the design of Logo as an object-to-think-with. This connection is in no small part due to Julie's use of constructionist technologies (e.g. LEGO Mindstorms, Snap!, and more) and the university programs that she collaborates with, but it is also embedded into her teaching style. For example, when asked to describe her teaching style, Julie explained helping a student explore the degrees of a right angle through programing a Mindstorms robot to move:

> One girl go[es], "Didn't move"... I go, "Yeah, it did move, you told it to go 90 degrees." I go, "Let's turn the wheel and actually put the [Sharpie] marks on the wheel turn, that's how far it went." [She goes] "Ohhhhhhh," and like you see the light bulb go off… so hopefully making some of those concepts a little bit more visual some way.

Yet, it is this approach to learning, one where learning happens through physical trial-and-error manipulation, that Julie believes runs up against traditional school structure.

Julie acknowledges the tensions between her own preferences and the school where she works when going on to clarify her teaching style,

> Back to your original question, my teaching style, I try and do more of learn while we do, versus the official, "Let me sit and teach you that," which kind of goes against all this new New York State APPR [Annual Professional Performance Review] testing because I'm expected for them to come out knowing… I look at my courses [as] exploratory not mastery and so I'm [at] a conflict with what they expect. And I want the kids to like class, I want them to like technology, not be afraid of technology...

Here, APPR refers to outcomes from 2010 legislation that made changes to teacher and principal performance evaluation that resulted in them being rated “highly effective,” “effective,” “developing,” or “ineffective” [29]. When this interview was conducted (spring 2015) there was a push by the state to make the APPR more tightly coupled with test scores, which is why Julie refers to “APPR testing.” With this in mind, the quote speaks to the challenges Julie believed she encountered when her teaching style and philosophy were pushed up against state and district policies and expectations.

LEGO Mindstorms and the FIRST Lego League

The majority of data collected and analyzed for this project is on Julie’s implementation of LEGO Mindstorms in-school, after-school, and at a regional FIRST Lego League competition. When this project started, Julie had been using Mindstorms in her classroom and after-school for the last ten years and had no plans of stopping in the near future. Mindstorms, as an educational technology and toy extension of LEGO products, is a proprietary programmable robotics kit that is owned by the multinational LEGO Group. For both the educational and entertainment versions, the centerpiece of the kit is called the *programmable brick,* which can be coded to manipulate motors and sensors.

LEGO Mindstorms and the programmable brick have firm roots in constructionism. At a surface level, its name references Papert’s 1980 book, *Mindstorms: Children, Computers, and Powerful Ideas* and during its early releases featured quotes by Papert on the product’s packaging (see figure 1). At a deeper level, its early development in the 1980s, called the LEGO/Logo project, brought together LEGO construction kit activities with the Logo programming language. The project was spearheaded by Papert’s colleagues and students (including Mitchel Resnick, Stephen Ocko, Brian Silverman, Fred Martin, and others) and made possible through a collaborative partnership between the MIT Media Lab and the LEGO Group.

Figure 1. RCX generation packaging from Julie’s classroom that features a quote by Papert.

As a cultural artifact, Mindstorms brings together the traditional characteristics of children’s construction kits (e.g. Lincoln Logs, K’NEX, etc.) with materiality and symbolism of robotics from popular entertainment (e.g. *Transformers*) and commercial industry (e.g. iRobot). As members of the LEGO/Logo development team, Resnick, Bruckman, and Martin [30] explained the brick’s unique contribution to the legacy of commercial and educational construction kits for young people: “Traditional construction kits enable children to build structures like bridges and buildings. Contemporary construction kits (e.g. LEGO Technics) add power and motion, enabling kids to build motorized cars, Ferris wheels, and other battery-powered machines. The MIT Programmable Brick adds a third level—sensing and control." There have been three generations of Lego Mindstorms since the LEGO/Logo project left the MIT Media Lab. The RCX generation was first launched in the late 1990s, followed by the NXT system that was released in 2006, and since 2013 the EV3 has been on the market. While Julie had used educational versions of all three generations, during the year in which data were collected for this project she used the NXT versions during in-class activities and the EV3 models after-school, as the latest version was required to prepare for and participate in the regional FIRST Lego League (FLL) competition.

Since 1998, FLL competitions have taken place through a partnership between the LEGO Group and the international non-profit, For Inspiration and Recognition of Science and Technology (FIRST). In the U.S., FLL is for elementary and middle school students, and since its founding it has had a strong focus on supporting young people's interest in engineering. FLL is just one of the competitions that FIRST supports across age groups. Other competitions include the FIRST Robotics Competition for high school students and FIRST Lego League Jr. for younger elementary school students. In terms of FLL specifically, the competition begins with a coach receiving, approximately eight weeks prior to the competition, a Challenge Set, which includes a table mat and obstacles or problems to solve with a Mindstorms robot. This is in preparation for the Robot Game, which is a two and a half minute autonomous robot run that students design and program to complete a "mission." Teams also must prepare for a Robot Design evaluation and a five minute research project that connects to the theme of that year (e.g. Nature's Fury (2013) or Trash Trek (2015)).

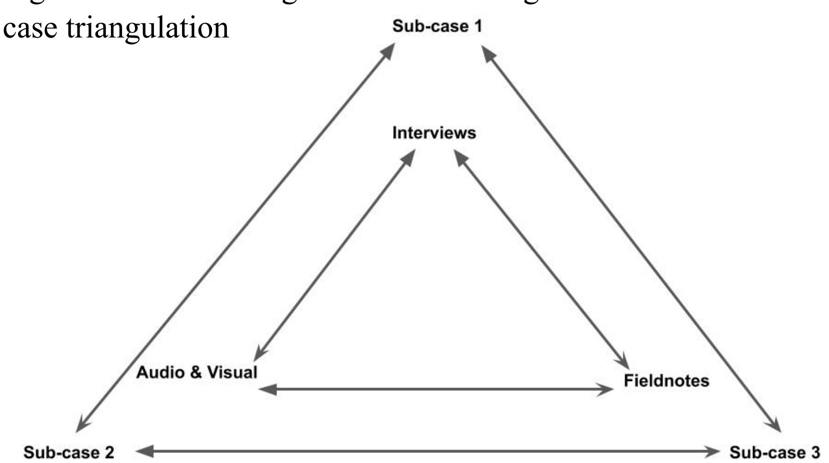
FLL, and FIRST more generally, takes place at regional, state, national and international levels. Though FLL competitions are structured like sporting events, with teams, coaches, and referees, the coach position is unlike the traditional sports coach in that knowledge of the game is not a prerequisite for gaining the position. Indeed, FLL coach handbooks tend to encourage adults to become coaches even if they do not have background knowledge about programming or engineering. Reporting on FLL participation in FIRST's 2018 annual report, "Approximately 280,000 9-16 year-olds on 35,033 teams from 98 countries participated in this season's Challenge" [31]. This speaks to not only the global reach of FLL but also the reach of Mindstorms and constructionism in supporting students' pre-college engagement with engineering.

Data Collection and Analysis

We use a descriptive single-case study research methodology to help answer our question about the constructionist positioning of the teacher in pre-college engineering education. Our choice of a descriptive case study design is appropriate for two reasons: 1) we are investigating a contemporary phenomenon in a "real-world context" (i.e. a teacher's use of constructionist technologies) and 2) the boundaries between the phenomenon and context (Julie's school and the FLL competition) are not clearly demarcated, which makes contextual conditions important to the analysis [8]. A case study methodology is not bound by any specific type of data but, more so than other methodologies (e.g. historical, laboratory, etc.), requires the convergence of different types of data sources for strengthening the validity and accuracy of the findings [8]. This means that case study research often requires multiple research methods for collecting data.

One way that validity can be constructed in case study research is through the process of comparing and converging multiple sources of evidence, otherwise known as “triangulation” [8]. For the case of Julie’s teaching and coaching, data included field notes, audio and visual materials (i.e. digital audio recordings and pictures), and a semi-structured interview. These were triangulated within three “embedded units of analysis”: “a unit lesser than the main unit of analysis, from which the study data also are collected” [8]. We call these “lesser” units *sub-cases*. Sub-cases were chosen because they represented general trends or themes in Julie’s teaching and coaching that were identified from field notes, an interview, audio and visual materials, and the general experience of collaborating with Julie by the first author. Below, we show how sub-case convergence affords two levels of triangulation. Figure 2 represents these two levels as, what we call, *nested triangulation.* Consistent with qualitative methodologies more generally, we triangulated different data types for each sub-case and then, more uniquely to case study research, triangulated the three sub-cases to interpret our main case: Julie’s teaching and coaching.

Figure 2. Nested triangulation: data triangulation nested in sub-case triangulation



The primary data used in this paper were collected over the course of one academic year. During the 2014-2015 school year, the first author used the ethnographic method of participant observation to study Julie’s implementation of LEGO Mindstorms in-school and while coaching for a FLL competition. From this year, fieldnotes, audio and visual materials, and an approximately 1h and 28min semi-structured interview transcript comprise the largest portion of our data. In addition, during 2016, 2017, and 2018 the first author collaborated with Julie to implement a suite of culturally responsive and constructionist-oriented visual programming environments called Culturally Situated Design Tools [32]. Exit interview transcripts from these collaborations were analyzed and sometimes included in the triangulation process.

Findings

Our findings are organized into three sub-cases that have been selected to highlight the more general case of Julie's pre-college engineering teaching and coaching. Consistent with her initial introduction above, the first sub-case shows some of Julie's constructionist tendencies while using Mindstorms to support an in-class Pi Day activity. The second sub-case details an instance where Julie demoed a pre-packaged lesson that connected engineering design via Mindstorms to the New York Common Core State Mathematics Standards for her math teacher colleagues. The third sub-case explores Julie's role as an FLL coach while she prepared for and facilitated students' participation in a regional competition. Overall, these sub-cases reveal how commitments to pre-college constructionist-oriented engineering education can result in "double binds" [9] where constructionism is simultaneously positioned as an advantage for students' learning and long term development but also a disadvantage to participating in larger educational structures in- and out of Julie's school.

Sub-case 1 - Pi Day

In 2015, Pi Day (March 14th; 3/14) fell on a Saturday. Therefore, Julie's Pi Day activities took place the following Monday, two days after Pi Day, on March 16th. For her Pi Day celebration, Julie used a lesson plan she had developed during a 2013 summer professional development program at a local engineering college. The lesson, titled something similar to "Robot Wheels", sought to connect Mindstorms to New York State's Common Core Learning Standards in Mathematics, specifically geometry content. The goal of the lesson was for students to explore the relationship between the distance the robot will travel and the circumferences of different wheels, which they determined through multiplying the diameter of the wheel and Pi (i.e. c=pi(d)). Julie pre-programmed and pre-built twelve NXT robots and organized them into boxes with a variety of exchangeable wheels, a couple of rulers, and a marker (see figure 3).

Figure 3. Materials for Julie's Pi Day Lesson.

Consistent with Julie's more general teaching style and philosophy, the Pi Day activity epitomizes the role of objects-to-think-with in discovering mathematical relationships and knowledge about the world. The goal was not direct instruction of some abstract mathematical formula that kids practice over and over again on worksheets, but, instead, the discovery of relationships through the concrete manipulation of computational artifacts (i.e. Mindstorms). At an even deeper level the activity represents a connection to constructionism's break with linear developmental stages, whether biological (e.g. operative stages) or institutional (e.g. grade levels), and toward a focus on "styles" [13].

For example, when asked about how she connects the robots to math standards, Julie was insistent on the importance of her role, as a technology teacher, in introducing young people to concepts that are traditionally above their grade level, whether it is introducing a seventh grader to eighth grade math or even to college level content. For example she explained:

> So I don't mind introducing the kids to stuff and like when we did all this [professional development] training [at the university], and I did mine on Pi Day or circumference or whatever you want to call it, somebody had said some[thing like], "Yeah, well that's really geared towards these grade levels" and I said… "But why?" I go, "[a colleagues name] you're first grade, why can't you be doing this? and saying, 'Hey when that wheel turns around one turn that's called the circumference of the wheel… and the point from the center out like along the spoke of this wheel, that's a radius'."

As this quote indicates, Julie appears rather indifferent toward traditional trajectories for when ideas and content should be introduced to young people. Whether she is reinforcing content learned in elementary school or introducing students to formulas used in college level courses on bridge construction, the goal is exposure and self-discovery through concrete material manipulation, not retention or memorization. At the same time, unlike some constructionist oriented technologists, Julie does not frame learning with objects-to-think-with as necessarily antagonistic to curriculum standards. As we will see in the next sub-case, Julie goes out of her way to try and blend engineering design and computer programming experiences with traditional math content, even when the barriers sometimes appear too obdurate for implementation.

Sub-case 2 - Robots in a Box

For a number of weeks during the spring of 2015, Julie and a student from her after-school robotics program were preparing to demo a Mindstorms math lesson for two math teachers and a math coach at their school. The demo built on a lesson Julie had developed the previous summer at a university professional development program and was designed to support 6th and 7th grade math standards on linear functions. Specifically, the robot would be used to collect data for a graph that demonstrates consistent change between dependent and independent variables. To begin, students would program a robot—using a visual programming environment—to move it forward for a certain number of seconds (variable y) and, iteratively, increase the seconds each run but with a consistent power level. They would then record the distance (variable x) as data in a table for how far it went each run. Students would then plot out the seconds and distances along y- and x- axes to see how the data creates a straight line on their graphs.

During the math demo, Julie and the student added a deeper hands-on component to the lesson by showing how the robot could be used to physically graph a linear function on the floor of her classroom. To make it more likely that the math teachers would adopt the lesson, Julie prepackaged everything from the robot materials to the worksheets. She called the pre-packaged materials “Robots in a Box” and had a vision that the math teachers would come to her room and check out as many Robots in a Box that they needed for their specific class. During the demo itself, the teachers were enthusiastic about the connections between the robot and the standards. However, in the weeks and months following the demo, only one of the teachers followed up, despite all their initial interests and Julie’s efforts to make implementation as easy as possible. The one teacher who did follow up was an academic intervention services math teacher, who works with children struggling to meet the learning standards.

When asked about why she thought more of the math teachers did not take advantage of Robots in a Box, Julie framed it less as a problem of individual interest or access—as she had provided most of the equipment, technical support, and content—and more so the time constraints that they are under as math teachers. She explained:

> Well going back to barriers in the building, time, now that I think about it. With the Common Core, this is day one, this is day two, this is day three, this is day four. And so it might be a barrier on how much hands-on for kids demo wise.

Julie went on to explain her dissatisfaction with these time constraints and how they can potentially disadvantage student learning and development:

> ...to me, that doesn't factor in - what if the kid doesn't know it or what [if] half of them don't know it? Where's that time? Because if we skip that now they're going to be behind on something else.

This is consistent with Papert’s critiques that the structure of school itself gets in the way of constructionist learning. This is one reason that constructionist technologies often find homes in out-of-school or after-school contexts where young people can have more agential power in directing and shaping their own learning experiences.

Sub-case 3 - FIRST Lego League

After-school, Julie runs a series of programs for young people to creatively explore technology in self-directed ways. One of the more structured after-school programs includes coaching a team of students for a FIRST Lego League (FLL) regional competition. At the time of this research, Julie had been coaching FLL competitions for over ten years. For 2014, the year this paper reports on Julie's coaching, the FLL theme was "World Class - Learning Unleashed," which was about 21st century knowledge gathering and skill development. Julie took her coaching role seriously and treated the FLL challenges as student-centered and self-directed. In discussing her approach to coaching she explained:

> I would come to robotics and I would sit back and I'm doing exactly what I'm supposed to be doing, nothing. The kids, I give them a general direction and they're taking over and that's what FLL is supposed to be. It's not supposed to be "hey how you building that arm, well why don't you do this for that arm"… I'll help, you know, give them thoughts to lead to but I am not going to say, "hey put the arm on, let me build a claw that does this" and I don't do any of that. But the best days are when I can sit back and do nothing and every single kid is engaged in something and working. That to me is the ideal day.

Indeed, this is how FLL coaches are encouraged to be; they act like a general manager who oversees that day-to-day practices run smoothly, supporting young people to learn through trial-and-error self-discovery. As one of the FLL *Coaches' Handbook* explained, "Do not worry if you are not an expert on some skill or aspect of the Challenge. You can work through it with your team. In fact, it may benefit your team. Children love to solve problems that befuddle adults" [33]. However, as Julie learned, this approach to coaching might not be shared by all adults who support FLL or robotics teams more generally.

The 2014 tournament itself took place on a Saturday in early December at a regional engineering college. Julie's team had been preparing for the tournament since late October and she felt that they were more prepared than teams from some previous years. However, in the end, Julie noted that her team did about the "same as every year." While students' seemed to enjoy themselves and they appreciated being part of the competition, her team's final ranking was in the bottom 25%. Julie and her team were not sore about placing lower than others and appreciated seeing the work the other teams put into their robots.

However, Julie did express disappointment about some comments from an adult that could be interpreted as saying that the coaches were taking too strong of a lead in designing, building, and programming the robots. She explained a conversation with an adult from a neighboring school while watching a high school robotics tournament together the following March:

> They [i.e. adult from a neighboring school] said "well we know who builds the high school robot, is it really the kids?" And he said, "same for us." And that was a total let down for me, but it explains why in the tournament they're so successful. But it also makes me feel good that exactly what I said, the days that I can just sit back and do nothing, the kids are doing the learning, the kids are doing the building, the kids are doing the problem-solving… It's the kids and that's what it's supposed to be. And like I said I keep them on track: "hey we gotta do some research" or "hey where are we with our missions…" I'll do those leading things, but.. after we went to watch the high school tournament... That was my downer

> when they said "well who do you think, you know, builds the high school robot? You know, hey I know how that feels" or some comment like that… Gee I really hope you're not telling the kids how to solve that mission. But in the same sense, even knowing that, I have no problem coming back [to my team] and saying hey maybe were they more focused?

While it is unclear if Julie's interpretation of the conversation was correct, it does suggest that if adults or coaches do not share the same commitments to constructionist-style learning (i.e. that which is self-directed and student-centered trial-and-error learning) when preparing for FLL competitions it might be a competitive disadvantage for the teams and coaches who do. Despite this knowledge, Julie's commitment to learning-by-doing, either after-school, at FLL, or during the school day, is process-oriented not outcome-oriented. Therefore, she did not appear deterred from continuing to coach in ways that she believes are best for student learning and development: letting them take the lead in learning, building, and problem solving.

Discussion

As demonstrated above, Julie has a strong commitment to supporting pre-college engineering education as constructionist-style teaching and learning. However, she does not always perceive this as aligning well with the larger educational structures in which she is situated, in-school, after-school, or out-of-school. Indeed, one can interpret the case of Julie's teaching and coaching as reaffirming the Logo revolutionaries' insistence that any failures of Logo to improve learning has less to do with the technology itself and more so the obdurate structures of schooling and narrow views of education. This helps us begin to develop a partial answer to our initial question: How does the constructionist positioning of the teacher play out in pre-college engineering education?

The case study of Julie's teaching and coaching reveals a situation where promoting constructionism was simultaneously positioned as a perceived advantage for student learning and development and also a perceived disadvantage to their institutional achievement in larger formal and informal educational structures. Julie provided a strong foundation for diffusing constructionist engineering design and computer programming in and out of her classroom, as seen in each of the sub-cases above. However, Julie's efforts were pushed up against curriculum or testing demands in-school and adults who do not share her same commitment to self-directed and self-discovery learning out-of school. Ultimately, we argue, this tension may place teachers who are committed to constructionism in a type of pedagogic "double bind" [9].

The concept of the double bind describes situations where contradictory demands are placed on individuals or groups. The concept is rooted in cybernetician, Bateson's work on family dynamics and communication patterns [9]. Bateson argued that schizophrenia might be a learned behavior from iteratively being placed in situations where contradictory demands are being made of an individual. Taken outside of the realm of mental health and psychology and into the field of anthropology, Fortun [34] explained the concept with the command "You must disobey me": "To obey the statement is to disobey it; to disobey it requires obeyance." In the case of Julie's teaching and coaching, she has the demand of educating young people. At one time, through expertise and experience, Julie believes that self-directed trial-and-error learning, often with technology, is one of the best ways to support student development. At the same time, knowing what is best for student development may not necessarily align with what achievement looks like at institutional levels, in- or out-of-school. There is no clear way to overcome such double binds but instead, as Julie shows, only ways to negotiate the spaces that they constitute.

We believe that the concept of the double bind is consistent with the historical relationships and tensions between constructionism/Logo and formal educational contexts. In formal education, teachers are centered as the sole bearers and transmitters of knowledge and expertise. Fitting with the traditional model of schooling, knowledge is defined as a set of immutable facts and procedures, and the teacher is responsible for transmitting this collection to the students in a formalized, procedural way [35]. The demand imposed by educational institutions on teachers to transfer knowledge in this way places teachers, like Julie, in a position where the demand is impossible to fill without sacrificing the broader experience and quality of learning provided by constructionist practices.

More unexpectedly, this double bind also appears in out-of-school contexts, in particular at FLL. Julie's FLL experience highlights the assumptive position that constructionist teaching practices are foundational to all that engage with FLL as a learning environment. Although Julie supported her team in preparing for the FLL competition through learning-by-doing, she questions if other FLL teams are guided by similar or different student-centered and self-directed approaches, which ultimately has implications for student learning and development and equitable competition rankings. While, we cannot know for sure within the context of the present study, this may reveal that if FLL coaches do not share the same commitments to constructionist-style learning and have, instead, favor a stronger hand in design activities it may be a competitive disadvantage for the teams and coaches who do favor more self-direction and trial-and-error learning.

Conclusion

From our case study on Julie's teaching and coaching, this paper suggests that constructionism might support deep forms of engineering design through material engagement, but that this can also complicate traditional expectations when it is pushed up against the traditional forms of achievement, such as curriculum standardization or placing well in a competition. While our present study allowed for us to explore Julie's use of constructionism and experience with Mindstorms, a limitation of this study is that it only captures one teacher's practices, beliefs, perceptions, and context. This limitation does not allow us to make any empirically comparative claims about FLL teams or the reasons for their achievement. In addition, we presented little in terms of data from or about how young people experience the tensions and double binds of constructionism.

Future research can use a multi-case study design to compare and contrast FLL coaches' and young peoples' practices and beliefs. More specifically, in what ways might social class shape FLL teams' preparations and performances? Future work could compare FLL teams from communities that represent different socioeconomic conditions. What is more, studying FLL teams from different racial and ethnic communities might help us think about culturally responsive robotics education. How might FLL teams engage with identities, heritages, families, and other local community assets as sources of socio-technical innovation to support their achievement at FLL competitions? These questions suggest that there is much work to be done by critical engineering researchers and pedagogues on the social, economic, and cultural factors that shape pre-college robotics competitions.

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