Engineering Discourse Development in an Informal Youth-Driven Maker Club

Sagit Betser, University of California Davis, sbetser@ucdavis.edu
Lee Martin, University of California Davis, leemartin@ucdavis.edu

Abstract: This paper investigates opportunities to learn engineering design discourse within maker activities. Drawing from a study of youth participation in an informal, out-of-school, youth-driven maker club this study investigates processes of discourse use and learning. This study contributes to the ongoing conversation in the learning sciences about how youth gain access to valued disciplinary discourses. The authors employ Sfard's (2008) commognitive framework to conduct a detailed examination of mentor-mentee interactions in order to uncover mechanisms of disciplinary learning. Findings suggest that youth can pick up aspects of discourse relatively quickly, but that negotiating discourses in real time can be challenging for both youth and mentors.

Introduction

There is a broad consensus that more work is needed to uncover the processes by which young people become interested and skilled in STEM fields. In this study, we report results from a study of youth participation in an informal, youth-driven maker club as a setting for engineering design learning. We view learning as a development of a specialized discourse (Sfard, 2008). While in formal learning setting like schools, one role of the curriculum and teachers is to introduce students to disciplinary discourse in explicit ways, in informal settings like the one examined in this study, these processes are usually implicit. The goal of this study is to contribute to the body of research that explores how disciplinary discourse develops in interest-driven youth-led learning environments.

A growing body of literature examines maker spaces and maker activities as contexts for STEM learning. One line of work examines the particular practices of making, and the opportunities that youth and other participants have to engage in those practices. Gravel, et al. (2015) found that experienced makers identify, organize, and integrate information across sources. Blikstein (2013) reports that youth who worked on projects using digital fabrication techniques received an opportunity to explore STEM concepts like electricity, magnetism and motion. Martin and Dixon (2016) describe opportunities to engage in frequent dialogic interaction around unexpected events within a community that values conceptual understanding – practices believed to foster the development of adaptive expertise. Halverson, et al. (2014) show the importance of the community within maker spaces, demonstrating the fluidity of mentoring in such spaces and its impact on just-in-time learning.

Others have looked for evidence of change over time. Fields and King (2014) found that college-age women in a craft technologies course changed their view of themselves and their ability to be designers of technology. Blikstein (2013) showed that youth in his studies showed increased interest in STEM fields. Bevan, et al. (2015) found that question development and moments of struggle were key learning indicators during tinkering. Dixon and Martin (2017) found that youth with more maker experience showed greater and more dynamic interactions within the community. Calabrese Barton, Tan, and Greenberg (2016) show how maker spaces can be important sites of identity development.

While the number of studies that investigate the potential of making and tinkering to STEM learning is growing, there is a need for additional work examining the mechanisms of learning in making and the way disciplinary discourse develops in these settings. The goal of this study is to contribute to this body of literature on STEM learning and making by focusing on practices of engineering design. From a disciplinary perspective, one important routine within engineering design is the design process (Dym et al., 2005). There are many different versions of the design process, but all share a commitment to iterative design: as the project moves forward, participants gain new insights that feed back to earlier stages, which may direct a new path for the project. For any specific stage in the process there are norms of what counts as acceptable contribution in that stage. To examine how young makers learn in an open-ended out-of-school learning environment, we closely track changes in engineering design discourse that take place during mentor-mentee interactions within work sessions of youth-driven maker projects.

Theoretical framework

This work is guided by sociocultural theory of learning, looking closely at the relationship between culture and learning as a social activity, where knowledge is built within a community of practice (Lave & Wenger, 1991). Our research uses Sfard's (2008) commognition framework, which views thinking as individualization of interpersonal communication and learning as change in learner's discourse towards becoming a participant in a community with a certain type of discourse. Discourse, according to Sfard, is a form of communication that defines a community and was developed along the history of a profession to answer certain communicational needs within that community. Each discourse is characterized by four features: (1) words and the way they are used as defined by the discursive community; (2) visual mediators that are operated upon as part of the process of communication; (3) routines, which are repetitive patterns characteristic of the way participants in a discourse act in specific situations; and (4) endorsed narratives, which are texts (written or stated) that the discourse community endorses as true.

Methods

The purpose of this study is to contribute to our understanding of how engineering design discourse develops in a particular kind of informal maker project work, where projects are driven by youth interests and are supported by disciplinary expert mentors. The research questions addressed in this study are: 1) What opportunities for disciplinary learning develop in open-ended interest driven maker projects? 2) What mentor-mentee interactions enable or constrain disciplinary learning?

Research context

The data for this analysis comes from a study of youth participation in *Maker Club*, an organization that brought together small groups of young makers and helped them find adult mentors suited to their interests. *Maker Club*'s goal was to support 8-to-18-year-old youth in creating and ultimately presenting projects of their own choosing at a local Maker Faire. The full study details the work of four separate clubs, but for this paper, we focus on one club consisting of five boys, ages 12 to 14, and three adult mentors. Three of the boys, Parker, Kobe, and George, had already worked together for two years designing two other projects for the Maker Faire. One of the boys, Barnes, joined the team for the second year. A fifth boy, Barkley, was new to the team and to the making experience. The three mentors each had different expertise. Betty, the mother of Parker and Barnes, was an artist and a home-school mom. She organized the group and most often took the role of coordinator. Stephen, the leading mentor, was a retired electrical engineer with vast experience in product design. He had also mentored the group in previous years. The third mentor, David, was recruited by Stephen midway through the project to help with the main mechanism, as he was a mechanical engineer with years of experience in design.

After several meetings of brainstorming project ideas, the team decided to build a human-sized "creepy" cymbal banging monkey, inspired by a figure in the movie Toy Story 3. Figure 1 illustrates the cymbal banging mechanism the group designed (left), and the final project as displayed at the Maker Faire (right).

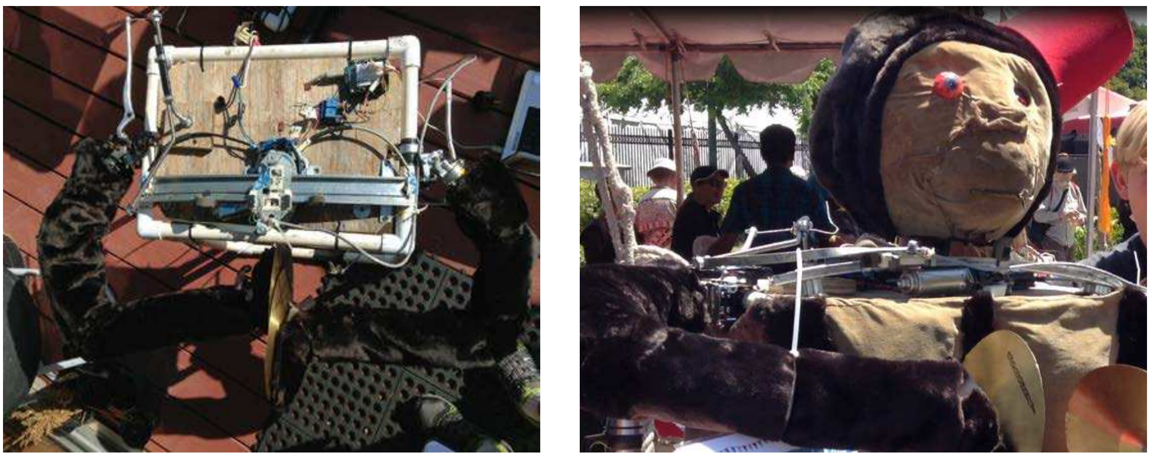

Figure 1. Cymbal Monkey mechanism and final product at Maker Faire.

Data collection and analyses

There were two main sources of data for this study. First, we took field notes and made video recordings of group work sessions. We observed seven collaborative work sessions of about two hours each, spanning around four months of work. Second, we conducted interviews with youth and adult participants. Data analysis started by transcribing all interviews and watching all seven work sessions and creating content logs. For this paper, we focused our analysis on observational data from the work sessions. For each session, we flagged moments of interaction between mentors and mentees. To allow a close look at changes in disciplinary discourse, we transcribed and then coded the first and last work sessions. Our initial coding pass was focused on differentiating broad types of mentor-mentee interactions: work discussion, demonstration, planning and management, building interactions, and social related interactions. For a second pass, we coded for the features of engineering disciplinary discourse and then looked for the following: changes in discourse, differences between participants, and instances where we should expect a potential for change even if it did not happen. This initial coding work was a preamble to our discourse analysis, which is the primary analytic method for this paper. The coding was a means to identify significant moments for further analysis.

Findings

The examples in this paper are taken from the first working session after the team decided on their project (the Cymbal Monkey). This session took place at Betty's home and was divided into three sections: brainstorm discussion, prototyping session, and wrap-up design discussion. Both the first and third sections were facilitated by Betty, who asked questions and kept the conversation focused, with the participation of four young makers and the leading expert mentor, Stephen.

In this section, we will highlight three aspects of discourse development in the setting. The first example contrasts the discourse of the newcomer with the oldtimers to illustrate the learning of the design process routine, a central routine in the work of a design project team. The second example tracks changes in a newcomer discourse and describes the mentor moves and mentor-mentee interactions that allow this change. The third example tracks a team discussion where we saw an opportunity for a shift in youth discourse that was missed in the moment.

Learning to be a part of a product design team

In the brainstorming discussion below, for example, the goal was to figure out how to design the monkey's main body. As a first analytic pass, we coded the contribution of each boy into one of three options (see Table 1).

Aligned: An utterance that relates to the design and aligns with the goals of this specific design process stage.

Not Aligned: An utterance that relates to the design but does not align with the goals of this specific design process stage.

Playful talk: An off topic, playful utterance, following Sullivan & Wilson (2015)

We can see that Parker and Kobe had a similar number of utterances both for aligned, not aligned and playful talk, while George and Barkley had notably different numbers of utterances. Because George arrived late to the session and entered the conversation much later we will not use his data in this analysis.

Table 1: Number of aligned, not aligned and playful talk utterances per participant

	Aligned utterances	Not aligned utterances	Playful talk utterances	Total
Parker	39	5	12	56
Kobe	42	5	13	60
George	13	0	2	15
Barkley	9	18	12	39
Total	103	28	39	170

The table shows that the number of playful talk utterances was similar between Parker, Kobe and Barkley. This similarity in playful talk may indicate that all three boys were comfortable socially in the space. However, comparing the number of aligned and not-aligned utterances shows that Barkley differed from Parker and Kobe. Barkley was the newcomer to the team, while Parker and Kobe were completing third maker project. This difference in experience could explain differences in his patterns of participation.

Guided by the two mentors, the two oldtimers (Parker and Kobe) brainstormed ideas for the design of the monkey body. They mentioned their past experiences, suggested materials, and identified possible solutions among known off-the-shelf products. Barkley, the newcomer, made fewer contributions to the brainstorming session, and when he did contribute, he mostly made suggestions for new features rather than solutions for the design problem under discussion, His new feature suggestions were not taken up by others in the group, likely because they were not appropriate to this juncture in the design process. The oldtimers replied with statements like "I don't think that's going to happen" or "I thought we figured that out last week."

We hypothesize that this difference between Barkley and the more experienced boys represents their prior learning of a particular design discourse, learning that took place over an extended period of time through repeated participation in design work.

Despite his relative lack of experience with design discourse, Barkley was able to make shifts in his contributions even on the short time scale of one design session. Table 2 presents some representative, contrasting examples of Barkley's contributions at the beginning and end of this one maker session.

Table 2: Barkley's statements at the beginning and end of one session

Beginning of session	End of session
"He's definitely coming up with the outfit. We could give him a scarf, top hat."	"So the cymbal, so there are these pieces of sponge on the bottom. And when, I, I was thinking that we could put them on the cymbals and when it will send, it will send volts through the arms. And you know how the motors reverse back into starting position"
"I think you guys should not do the moving arms thing and like if he is gonna be dressed up in a thing, like a high fashion thing he should like do this like … I mean you would press a button and like he would say like 'High Fashion'. And you could raise – you could just make like something that would make his chin lift up"	"Because a sponge, sponge. Well I thought with this sponge here, we could wire it up to something, and uh electric, electric, electricity. This is what this is. When these touch they tell you. It. The electricity goes through and that tells the gears, oh, turn it back. And when it goes back it starts the routine over and over"

Reading Barkley's contributions closely, and watching how he presented them, we saw a difference in his choice of words and the visual mediators, both important characteristics of a discourse in the commognition framework (Sfard, 2008). . While at the beginning of the session Barkley was focused on the way features looked or the way the user interacts with their functionality, at the end of the session he took up the group's focus on the way things actually operate, including the hidden mechanisms that control their operation, while incorporating engineering words like *volts*, *motor*, *reverse*, *wires*, *electricity*, *gears*, and routines like taking apart and using it in a new way.

Mentor-mentee interactions

To understand what may have led to this change in Barkley's discourse, we analyzed the expert mentor moves and interactions with the boys during the session. The mentor, as an expert in the engineering discourse, introduced the boys to engineering narratives, modeled design routines, and emphasized engineering vocabulary within conversations with youth about their ideas. To illustrate this process, we present a moment where the mentor coupled talk about the engineering concept of *feedback* with an engineering routine of disassembling a product to see how it works. We show how Barkley made attempts to gain access to the engineering discourse through explorative imitation of the mentor's discourse and physical manipulation of materials.

At the beginning of the session, the mentor, Stephen, brought a printer to the table and took apart the modules to illustrate the idea of feedback in the printer's design. Stephen did not explicitly define feedback, but he described the way the idea of feedback is realized in the printer design.

"So that's kind of a feedback thing, where you have a motor that moves something and then something else that tells it where it is. And then you can get it to go to the right spot. That's a common thing you run into – the combination of a motor and a sensor connected together with a computer."

When Stephen used the printer to introduce feedback, he also demonstrated an engineering design routine: taking apart designed objects to learn how they work in order to inform the current design. Here again we see an important characteristic of a discourse, a *routine*, modeled by the expert. Barkley used this routine later in the session, when he decided (without prompt) to take apart a video game controller that was brought by the mentors to the work session. He took apart the controller and, prompted by the mentor, examined ways to use its parts in the mechanism of the cymbals.

Speaker	**Speech**	**Gesture**
Barkley:	Can I take this apart?	Pointing the game controller
Stephen:	I thought we were building a monkey.	
Barkley:	I need to take it apart 'cause someone jammed this piece in. I need to get something. Anybody have – do you know where a screwdriver is?	Holding the controller
Betty:	Here's one. It's a Phillips though.	Give it to Barkley
Stephen:	Did you figure out how the buttons worked?	After some time of work, when Barkley took out some parts, Stephen approaches him
Barkley:	Yeah, so they're actually magnets.	
Stephen:	Actually they're just conductive material. It's not a magnet, it's just any kind of metal that – or something that conducts electricity. And so there's a little set of fingers that goes like this and a little set of fingers that go like that and if they both make electrical contact between the fingers that closes the circuit.	Using his own fingers to demonstrate how the electric circuit looks like
Barkley:	We could use this.	
Stephen:	You could use that.	
Barkley:	Huh. That's always good.	
Stephen:	What do you want to do when the switch closes?	
Barkley:	Oh, when the switch, when the switch closes, we could make his fingers go like this, like	Using his fingers to demo
Stephen:	I thought he was gonna have cymbals in his hands	
Barkley:	Oh, we could do it on the cymbals	
Stephen:	So that little black thing in there, that's conductive foam. It's conductive like this. It's really soft rubbery stuff.	Pointing to the part in Barkley's hands
Barkley:	You could put those on the cymbals, and when the cymbals touch, it would make them go back to their position.	Demonstrate with the part in his hands
Stephen:	So when they touch, that would tell the motor to reverse direction.	

Barkley:	Yeah, reverse	
Betty:	We're, boys, we're pretty much done, so you're gonna draw up some sketches and –	Everyone sitting around a table
Barkley:	I'll sketch.	Opens his notebook and draw his idea
Kobe:	What's that?	Approaching
Barkley:	So the cymbal, so there are these pieces of sponge on the bottom. And when, I, I was thinking that we could put them on the cymbals and when it will send, it will send volts through the arms. And you know how the motors reverse back into starting position?	Pointing to his sketch while explaining
Kobe:	It depends how far it is.	
Barkley:	Yeah. This is easier. Because then when they touch it just throws it back	
Kobe:	Yeah, but it's more wiring on the cymbals. Plus they'll be obvious. Like people will see it.	
Barkley:	Or you can cut a hole in the cymbals	

In this interaction we see Barkley took initiative and took apart a game controller. This action diverges from the main activity, but the mentors do not stop him or tell him to join the main activity. We see several examples of Barkley's explorative imitation of Stephens' discourse – the use of fingers, the use of engineering vocabulary, and the parallel reasoning about feedback in Barkley's cymbal mechanism that resembles Stephen's explanation of the printer mechanism. The move between physical objects, embodied modeling, and talk allows Barkley to imitate in an explorative way and to move from a peripheral participation at the beginning of the session to fuller participation later on when he sketches ideas for a presentation and gains the attention of one of the more experienced boys.

A missed opportunity for discourse development

An environment like this also presents challenges to mentors when opportunities arise in the moment and are not always easily picked up. One example of such instance happened during a discussion on the next step in the design of the monkey. The main participants in this discussion were the three oldtimers, Parker, George, and Kobe, and the two mentors, Betty and Stephen. Betty managed the discussion about the "skeleton", asking the team to brainstorm ideas on "what is the project's skeleton made of". Table 3 offers a transcript of this conversation with our interpretations for the statements.

Table 3: The 'skeleton' discussion

Speaker	**Speech**	**Interpretation**
Betty:	Ok, so if we say the next step is the skeleton, then what is the skeleton made of?	
Parker:	The skeleton should be made of foam and we should wrap it in fabric and awesomeness.	For Parker, the skeleton functions also to set the shape of the monkey
Kobe:	We could make the thing out of foam, right? And then we could uh We could take like – you could make a mold of it and make it like a hollow thing.	For Kobe, the skeleton also functions as setting the shape.
Stephen:	I, I was sort of visualizing kind of a frame board made out of metal or wood or something.	For the mentor, the skeleton functions as a structural support

Betty:	[to George who just arrived] So we're going to catch you up to date to where we're at right now. We've talked about some ideas for materials. Or first we asked what was the next step. And then people answered skeleton and we talked about ideas for materials for the skeleton, we said foam or layered cardboard or wood or aluminum.	Betty at this stage is familiar with all participants' ideas. Her interpretation of the discussion is from a material perspective and not a functional one.
George:	Wood seems kind of hard to cut it into the shape of a skeleton. Couldn't we – I kind of like claymation where you have a little thing and then you put wires.	George interprets the word "skeleton" in its everyday use (e.g. skeleton of a human body).
Parker:	Couldn't we technically use one of those ceramic skeletons they have in like horror, or like molded skeletons out of plastic or something? Like they have in classes and stuff. Like a skeleton of a human and the skeleton of a monkey are kind of kind of close.	Parker, too, interprets the word skeleton in its everyday human-body context.
Kobe:	What if you got a little store mannequin and made it sit down and just made it look like a monkey. Because it's already hollow. It's already strong.	Shape and support.
Stephen:	I'm just thinking, it would just be…it would just be like a rectangular solid thing. You know like four sides, four posts.	Stephen restates his frame idea. This time he addresses implicitly the shape argument by emphasizing that the frame can be rectangular (not a body shape).
Kobe:	What happened to the mannequin? That was a genius idea.	Kobe advocates his idea.
Stephen:	Make a square – a rectangular base, a rectangular top. And then start adding stuff around the outside of it.	Stephen restates the idea of the frame as a structural support.
Kobe:	Mannequin mannequin	Kobe expresses his frustration.
Kobe:	Stephen, I challenge you to a battle of wits.	
Stephen:	Uh oh.	

This conversation is an example of a commognitive conflict (Sfard, 2008). A commognitive conflict happens when participants in a conversation actually participate in two different discourses. In this case, we can see that Betty and the boy's discourse is based on an everyday discourse of designed objects. In their discourse, skeleton embodies both the shape and function of an object. In a design engineering discourse, a skeleton is a structural support to which modules are attached (Slocum, 2008). Therefore, there is no required connection between the form (shape) and the functionality of the object. The frame can serve the function of structural support without attending to the shape requirements, an engineering narrative of the separation of form and function. Stephen's discourse is a professional engineering design discourse. When engineers work on product design, they take into account different requirements: for example, mechanical (e.g. mechanisms), structural (e.g. stress, flow), and industrial design (look and feel). They separate functionality requirements from shape requirements to maximize degrees of freedom in the design. The mentor, who is the expert in the professional discourse, is the only person who can expose the conflict to the group and introduce the other participants to the rules of his discourse. However, Stephen did not make any moves to do so here. He missed the opportunity to develop the young makers' disciplinary discourse. We do not mean this as a critique, but rather note it as an example of the challenges of negotiating this complex discourse space on the fly.

Conclusions and implications

Learning can be viewed as a development of a specialized discourse. In formal settings, introduction to disciplinary discourse can be an explicit goal of instruction, but in informal, youth-driven, and/or project based learning environments, those processes can be implicit. As a field, we need good models and examples of how young people develop disciplinary discourse in such settings.

Youth participation in making and the maker movement is a germane setting to investigate these issues. Many have identified making and tinkering as spaces where youth can gain access and experience with STEM disciplines in an informal, youth-driven space. While some have noted the topical and practice-based connections between making and STEM fields (and engineering in particular), there has been less work to examine precisely how making can help youth develop these disciplinary discourses. This study employed Sfard's (2008) commognition theoretical framework to investigate a group of young makers and their mentors. We identified moments where youth exhibited shifts toward disciplinary discourse, and the mentor moves that preceded these shifts. We also identify moments of communicational conflict where mentors and youth seemed to "talk past" each other and did not shift their discourses.

This study contributes to the ongoing conversation in the learning sciences about how youth gain access to valued disciplinary discourses. It does so within the context of the maker movement, a genre of learning environment that has recently gained traction in the field. In doing so, we also bolster claims that making can be a productive site for learning STEM, while also highlighting the fact that such learning is not automatic, but depends on careful articulation between mentors and youth.

References

Barton, A. C., Tan, E., & Greenberg, D. (2016). The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. Teachers College Record, 119(6).

Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2015). Learning Through STEM‐Rich Tinkering: Findings From a Jointly Negotiated Research Project Taken Up in Practice. Science Education, 99(1), 98-120.

Blikstein, P. (2013). Digital fabrication and 'making'in education: The democratization of invention. FabLabs: Of machines, makers and inventors, 4.

Dixon, C., & Martin, L. (2017). Make to Relate: Analyzing Narratives of Community Practice. Cognition and Instruction, 35(2), 103-124.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. Journal of Engineering Education, 94(1), 103-120.

Fields, D. A., & King, W. L. (2014). So, I think I'm a programmer now. In Developing connected learning for adults in a university craft technologies course. In Polman, JL, Kyza, E. A., O'Neill, DK, Tabak, I., Penuel, WR, Jurow, AS & D'Amico, L.(Eds.).(2014). Learning and Becoming in Practice: The International Conference of the Learning Sciences (ICLS) (Vol. 1, pp. 927-936).

Gravel, B. E., Tucker-Raymond, E., Kohberger, K., & Browne, K. (2015). Literacy practices of experienced makers: Tools for navigating and understanding landscapes of possibility. In Proceedings.

Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. Harvard Educational Review, 84(4), 495-504.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge Univ. Press.

Martin, L., & Dixon, C. (2016). Making as a pathway to engineering. Makeology: makers as learners, 2, 183.

Sfard, A. (2008). Thinking as communicating: Human development, the growth of discourses, and mathematizing. Cambridge University Press. Sheridan, K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. Harvard Educational Review, 84(4), 505-531

Slocum, A. (2008). Fundamental of Design Topic 4 Linkages. Jan, 1, 62.

Sullivan, F. R., & Wilson, N. C. (2015). Playful talk: Negotiating opportunities to learn in collaborative groups. Journal of the Learning Sciences, 24(1), 5-52