Influence of Public Design Critiques on Fifth Graders Collaborative Engineering Design Work

Michelle E. Jordan, Arizona State University, Mary Lou Fulton Teachers College, Farmer Education Building
1050 S Forest Mall, Tempe, AZ 85287–1811, Email: Michelle.e.jordan@asu.edu

Abstract: Understanding how young students learn to engage in collaborative design practices entails understanding social interaction processes that occur beyond collaborative groups. The purpose of this study was to understand how talk generated during whole-class public design critique sessions influenced collaborative groups in subsequent small-group work sessions. Analysis focused on data from one fifth-grade class in which students were challenged to collaboratively design, build, and program robots. Video-recorded and transcribed whole-class interactions from three design critique sessions across the second, third, and fourth day of a 14-day robotic engineering design project were examined in order to categorize the types of comments made by the teacher and students relative to the nascent design solutions of three focal groups. Collaborative discourse from subsequent small-group work sessions was then examined in order to understand what ideas students took up, as well as how they took them up and to what effect.

Introduction

Grounded in socially oriented theories of learning that emphasize the role of social interaction (Bransford, Brown, & Cocking, 1999; Greeno, 2006; Rogoff, 1990), learning scientists frequently attend to important dimensions of interactional patterns among group members for increasing the potential of learning from collaborative experiences. Fewer scholars have investigated how social interaction in the broader classroom context (i.e., with classmates and teachers) influences small-group collaborative project experiences and outcomes (but see Greiffenhagen, 2012; Roth, 1995). Such investigations, motivated by a learning sciences' focus on authentic learning in complex contexts, needs to include research on ill-structured problems and design projects because such experiences entail the complex authentic tasks that learning and becoming in practice entail. Thus, the study described here focuses on one important practice identified in the ICLS 2014 conference theme, *engaging in design,* by exploring learning opportunities afforded through design critique processes related to fifth graders' collaborative engineering design projects. Drawing on data from a 14-session challenge to collaboratively design, build, and program robots, analysis focused on social interaction that occurred around three public design critique sessions in which students presented their engineering projects-in-progress and received formative feedback from their teacher and classmates. Two research questions guided analysis:

- What was the nature of talk elicited from the teacher and students during the design critique sessions?
- How did students take up ideas from design critique sessions in subsequent small-group work sessions?

The aim of the study was to understanding how public design critique processes influence the design activity of early adolescents learning to engage in collaborative engineering design in order to increase knowledge of how classroom-level social interaction influences learning from collaborative design projects.

Theoretical Framework

Learning scientists and educational researchers increasingly investigate the use of engineering design projects with children and young adolescents as understanding of the affordances of design for learning increases (e.g., Kafai & Ching, 2004) and as K12 engineering education gains prominent attention (e.g., NRC, 2009, 2011). Helping learners engage in engineering design favors project-based instruction as design tasks are open in their problem specification and solutions (Dorst, 2003). Constructionist theorists emphasize that learning is more effective when children make their own projects, construct their own ideas, and design their own solutions to problems (Bers, 2008, Papert, 1980). Furthermore, design activities have been shown to be more effective than direct instruction for helping students learn complex science concepts (Hmelo, Holton, & Kolodner, 2000) and helping students see the connections between science concepts and solutions to real world problems (Kolodner et al., 2003). Engineering design projects not only help students improve their ability to build things, but also understand what the building of things entails (Sadler, Coyle, & Schwartz, 2000). Additionally, the ill-structured nature of such projects can help students learn to cope with the uncertainty inherent in design endeavors (Jordan & McDaniel, in press). Finally, engineering design projects may be particularly effective for engaging young girls and other under-represented students in STEM learning (Laursen, Liston, Thiry, & Graf, 2007). These are compelling reasons for K-12 educators to create and implement engineering design projects. Yet, there is still much to understand about the social interaction processes that facilitate learning from such projects.

More broadly, design tasks entail the creation of an idea or physical artifact through thinking and manipulating tools and/or materials. Design practices cut across disciplines, and design literacy is seen by some scholars and practitioners as a crucial need of the 21st century (Pendleton-Jullian & Brown, 2011). Design practices have most often been investigated in fields such as architecture, engineering, and computer programming, and in the post-secondary education literature pertaining to those fields. Design tasks are underdetermined because a design cannot be fully defined by the problem statement. Designers must rely on creativity to generate a unique product. However, they are not free to invent anything; problem constraints partly determine a problem. Engaging in design involves iteratively redefining the problem and choosing among multiple paths that can be taken to infinite, unpredictable solutions (Jonassen, 2000).

Social interaction plays critical roles in design endeavors. Design is situated action that takes place over time through social interaction and reflection (Fleming, 1998). Communication among engineering team members is widely recognized as a fundamental aspect of design processes (Darling & Dannels, 2008) and learning to design (Jordan & Babrow, 2013). Engineering design also requires the ability to communicate effectively beyond the design team through online and face-to-face mediums (Jordan, 2014; Otto & Wood, 2000). Most notably for the purpose of this study, *design critique sessions* (DCS) are important opportunities for social interaction to facilitate learning. Used extensively in settings such as art schools, design studios, and engineering labs, DCS usually consist of public formative feedback related to an individual or group's ongoing designed project (Sawyer, 2012). The importance of DCS lays in that the teaching of design depends on communication among design students and teachers. Social interaction during DCS consists of cyclical processes of "telling and listening" and "demonstrating and imitating" (Demirbas, 2001). It draws attention to efficient and effective solutions as well as to design inconsistencies while facilitating knowledge exchange related to procedural aspects of design (Uluoglu, 2000). Ideally, students develop arguments about the validity of design solutions, defend their solutions, develop ideas and refine their projects (Schaffer, 2003). However, critical feedback can be difficult for students to accept and make use of in subsequent drafts of design work.

Previous analysis focused on discourse in the DCS, identifying shifts in social interaction patterns that signaled learning across the three design critique sessions. These included shifts (a) from talk focused on helping students deal with negative feedback to helping students consider needs of the customer, (b) from talk in which classmates talked only to the teacher and the presenters to talk in which classmates talked to presenters and to each other, the use of only sketches in presentations of design solutions to use of built structures and websites as discursive tools, (c) from reliance on self-generated design ideas to accepting and valuing remixes of other's creations incorporated into designs (See Kafai, Fields, & Burke, 2010), and (g) from reporting design ideas to co-constructing design ideas. Additionally, across the DCS, there was an increase in authority taken up by students, and a focus on structures and functions gave way to integrated talk about structures, behaviors, and functions (Jordan, in press). The current study builds on these findings by conducting a more fine-grained analysis of discourse related to three focal groups' design solutions during DCS and by expanding analysis to investigate the influence of those sessions on subsequent collaborative interactions.

Methods

The setting for this study was a regular fifth-grade class in a suburban school district in the southwest US. The 24 ethnically and academically diverse students in the class included 15 girls and 9 boys. Their teacher, Ms. Stevens (all names are pseudonyms), had 20 years of experience and was recognized in the district for her expertise in STEM instruction. Engineering experiences were part of the regular curriculum in this class. Ms. Stevens implemented instruction primarily around engineering challenges utilizing Lego robotic Mindstorms kits. Students engaged in three collaborative engineering challenges across the school-year, working in three-to-four-member groups and changing membership for each project. Projects 1 and 2 were well-structured tasks pre-determined by the teacher to help students learn collaborative engineering knowledge and practices. Project 3 (the focus of this study) was an ill-structured design task: to design, build and program a robot to address an environmental problem identified by each group. Six four-member groups were assigned by the teacher for this project. Three of those groups, each of whose membership was diverse in gender, ethnicity, and academic achievement, were selected for focal analysis. The Water Washer group created a remote-controlled paddle boat to clean lake pollution. The Claw Grabber group designed a wheeled-vehicle with a claw operated via touch-sensors to pick up trash for people with mobility impairments. Finally, the Recycling Rover designed a vehicle with a trailer that operated via a light sensor, transporting recyclable materials down colored paths.

During Project 3, the teacher organized instruction around 14 instructional days across one month, during which small-group work sessions were punctuated by whole-class mini-lessons (just-in-time topics) and teacher check-in meetings. The analysis described here focuses on data associated with the first four days of the project. Day 1 began with each group brainstorming possible projects. On Day 2, after settling on and sketching out their initial designs during a 40-minute work session, the class was called together by Ms. Stevens and DCS1 convened. Each group in turn presented their project progress and received critical feedback and design ideas from their teacher and the rest of the class. Members of a presenting group clustered at the front of the room around a document camera and a computer used to project artifacts on a Smartboard. Physical artifacts came into play as students displayed sketches, structures, and websites to explain and defend their design decisions. The teacher then led an evaluative discussion, offering questions, critiques and suggestions, and eliciting them from students. Two more DCS were convened over the next two days, interspersed between work sessions during which groups continued to refine and prototype their design ideas.

Data consist of (a) video recordings and transcripts of each DCS, (b) transcripts of work sessions pre and post DCS for three focal groups, (c) expanded observational field notes, (d) transcripts of semi-structured interviews with students and the teacher, and (e) artifacts associated with the project (i.e., photos of structures, written reflections, project wiki pages, computer programs). The first step of analysis was to create content logs of video recordings of DCS and all small-group work sessions of the three focal groups. Next, transcripts of all DCS were created and checked to verify accuracy. I drew on structure-behavior-function (SBF) theory (Hmelo-Silver & Pfeffer, 2004) to categorize the nature of talk generated during the DCS sessions for each group. *Structure* refers to the physical nature of the engineered system that students were designing, including how parts were connected (e.g., "Is that attached to the transporter?"); *behavior* refers to mechanisms that allow the function to be carried out (e.g., "You can program it to read different things on one program, too"); and *function* refers to purpose of the system or a subsystem (e.g., "That's a large-scale recycling; it's not just about keeping my house dust free"). Turn-by-turn analysis was conducted to identify the number of comments related to each category that were elicited by the teacher and by students, including statements, ideas, and questions.

The next step of analysis focused on understanding how the talk in DCS influenced subsequent small-group interaction. This step was informed by and sociolinguistic analysis of discourse (Erickson, 2004) and interaction analysis (Jordan & Henderson, 1995) in that is focused on identifying how events were structured, how artifacts and tools were used, and how participants were making sense of each other's actions as they related to collaborative design processes. In keeping with the goals of these analytical frameworks, I examined social interaction in the focal collaborative groups prior and subsequent to DCS to identify regularities in how participants within and between groups utilized social and material resources available in the context in which they were operating (e.g., ideas generated in DCS). Making extensive memos and annotations, I examined ways in which the three focal groups took up opportunities that were afforded in the three DCS for learning and making progress with their robotic engineering design project. Finally, I identified progress on each group's project pre- and post-critique design sessions. Throughout analysis, trustworthiness was addressed through prolonged engagement, analysis of multiple data sources to triangulate emerging interpretations, and multiple viewing of recording with peer reviewers.

Findings

Comments Elicited During Design Critiques

Table 1 shows the number of comments offered by the teacher and by students during the design critique sessions as they related to structures, behaviors, and functions of the three focal groups' design solutions. It thus provides an overview of what was discussed as well as an indication of how discourse about design solutions changed over time. Overall, more talk focused on structures (total of 78 ideas) than behaviors (total 53) or functions (total 44). Teacher comments were more evenly spread across the three categories (48:34:39), while more than half of the student comments pertained to structures (30:19:5). This finding is consistent with past research that novices tend to focus on perceptually available system components (i.e., structures), whereas experts cohesively integrate structural, functional, and behavioral elements (Hmelo-Silver & Pfeffer, 2004). Across the three DCS, the number of SBF comments generated in each session dropped for all three groups. Also, the proportion of teacher-generated ideas decreased over time, relative to student-generated ideas, in all three groups. For the Water Washer and Claw Grabber groups, more comments were elicited from students than from the teacher in DCS3.

Table 1: Ideas elicited across three design critique sessions

	Water Washer Group				Claw Grabber Group				Recycling Rover Group*		
		DC1	DC2	DC3		DC1	DC2	DC3		DC1	DC3
Teacher-generated ideas	Structures	10	16	1	Structures	4	1	1	Structures	9	6
	Behaviors	8	6	4	Behaviors	5	5	0	Behaviors	6	0
	Functions	23	1	1	Functions	6	1	0	Functions	7	0
		DC1	DC2	DC3		DC1	DC2	DC3		DC1	DC3
Student-generated ideas	Structures	2	8	11	Structures	2	0	1	Structures	3	3
	Behaviors	3	4	1	Behaviors	1	3	4	Behaviors	1	2
	Functions	3	0	0	Functions	1	0	0	Functions	1	0

*note that the DCS sessions were only convened for the Recycling Rover group two times

The Water Washer group garnered the largest number of SBF comments in all three DCS. Their early struggles to design a robot that met the specification to address an environmental problem were evident in the first DCS, during which the teacher presented 28 ideas related to the function of this group's design ("a robot to heat and cool and clean your pool"). That the group successfully re-tooled the function of their robot subsequent to DCS1 is reflected in a shift in DCS2 and DCS3 toward comments about structural aspects of their design.

The Claw Grabber group garnered the lowest number of SBF comments from the teacher and from their classmates. Their total of 35 ideas was far less than the 110 garnered by the Water Washer group and even less than the 40 garnered by the Recycling Rover Group in just two DCS. Perhaps the teacher and students alike shied away from critiquing this group in which one member, Adriana, became visibly upset after the teacher negatively critiqued the group's original design for a robotic tire pressure reader. Although the teacher ended this group's DCS1 with, "I'm going to have you all work on that a little bit more," the group ultimately dropped the idea. Following DCS1, they went back to the drawing board and brainstormed an initial conception of their Claw Grabber robot. This idea was ratified by the teacher in a small-group meeting prior to DCS2, which might be why the teacher contributed fewer SBF comments during this group's DCS2. The majority of comments offered to this group during DCS2 were about behaviors as the teacher questioned how the group could make their robot turn when they had only three motors (a design constraint), and the class struggled to understand how a person with mobility impairments could operate the remote control. Many comments during DCS2 expressed doubt about how the group planned to use a sound sensor as part of their propulsion system, an idea the group later abandoned when the programming proved too difficult.

How Ideas Were Taken Up

Ideas from the design critiques were taken up by all three focal groups following each DCS in which a group presented, though not always in expected or productive ways. Across the three DCS, groups seemed to increase their ability to take up teacher and peer feedback from DCS. Additionally, the largely positive affect with which they interpreted their DCS experiences was reflected in subsequent interviews. To illustrate, the following excerpt shows the integrated response of the Water Washer group to a suggestion made by a classmate about a structure associated with their design solution (i.e., the shape of their paddles).

Excerpt 1 (Water Washer group post-DCS3)

Ida: Adam raised his hand and said how about make them oval shapes, so that's what I think we should do.
Bobby: He said it should be oval.
Dante: That's not oval.
Interviewer: What did you guys think when Ms. Stevens asked the class if they had any suggestions?
Ida: I thought there would be a lot more people giving suggestions.
Roy: I like Adam's//
Dante: //I didn't think there would be a whole lot of suggestions though.
Roy: Me neither, but I liked that they were giving us ideas. But I think the tire might be a little heavy.
Dante: Yeah, because I think it'll spin and then this would leak, push it through the water faster and have more power so it'll go faster. And then I started to agree with my group because tires they're too thick and they make too much splash and it might not move through the water.
Roy: Yeah, I think it was a good idea, but I think we should stick to our sticks, but//
Ida: //It's a good idea, but still, that's more weight adding up, though.
Roy: Yeah.
Ida: It's just more weight adding up. It was a good idea though.
Bobby: Yes it was.
Roy: It was a very good idea.

Conclusions and Implications

This study is one step in a line of scholarly inquiry investigating the influence of whole-class social interaction in learning to engage in collaborative design projects. Findings contribute to understanding how talk elicited in DCS influence the design activity of early adolescents learning to engage in collaborative engineering design by categorizing the nature of talk in DCS by the teacher and students relative to the nascent design solutions of three focal groups, and by examining the subsequent discourse in small-group work sessions to see what ideas students took up as well as how they took them up and to what effect. The ultimate value of the study is its potential to impact learning-teaching practices related to engaging in collaborative engineering design processes. For instance, results could guide strategies for (a) structuring public critique processes to enhance students' learning to design and learning from design, and (b) helping students make use of critique in subsequent collaborative sessions. Findings may also illuminate learning-teaching processes in art settings, composition classes, or design studios - contexts in which public design critique is a long-standing practice.

References

Bers, M. U. (2008). *Blocks to robots: Learning with technology in the early childhood classroom.* New York: Teachers College Press.

Bransford, J. D., Brown, A., & Cocking, R. (1999). *How people learn: Brain-mind experience and school.* Washington, DC: National Academy Press.

Darling, A. L., & Dannels, D. P. (2008). A report on the role of oral communication in the workplace. *Communication Education, 52*, 1-16.

Demirbas, O. (2001). *The relation of learning styles and performance scores of the students in interior architecture education*. Unpublished PhD dissertation, Bilkent University, Ankara.

Dorst, K. (2003). The Problem of design problems. *Design thinking research symposium, Sydney, 17*(19-11).

Erickson, F. (2004). *Talk and social theory.* Malden, MA: Polity Press.

Fleming, D. (1998). Design talk: Constructing the object in studio conversations. *Design Issues, 14*(2), 41-62.

Greeno, J. G. (2006) Learning in activity. In K. Sawyer (Ed.) *Handbook of the Learning Sciences* (pp. 79-96). Oxford: Cambridge.

Greiffenhagen, C. (2012). Making rounds: The routine work of the teacher during collaborative learning with computers. *International Journal of Computer-supported Collaborative Learning,* **7**(1), 11-42.

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *Journal of the Learning Sciences*, *9* (3), 247-298.

Hmelo-Silver, C. E. & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science, 28*, 127-138.

Jonassen, D. H. (2000). Towards a design theory of problem solving. *Educational Technology, Research and Development*, *48*(4), 63-85.

Jordan, B. & Henderson, A. (1995). Interaction Analysis: Foundation and Practice. *Journal of the Learning Sciences, 4*, 39-103.

Jordan, M. E. (in press). Exploring how public design critique processes shape fifth graders' peer interaction during collaborative engineering projects. *ASEE proceedings,* Indianapolis, IN.

Jordan, M. E. (2014). Interweaving the digital and physical worlds in collaborative project-based learning experiences. In D. J. Loveless, B. Griffith, M. Berci, E. Ortlieb, & P. Sullivan (Eds.), *Academic knowledge construction and multimodal curriculum development* (pp. 266-284). Hershey, PA: IGI.

Jordan, M. E. & Babrow, A. S. (2013). Communication in creative collaborations: The challenges of uncertainty and desire related to task, identity, and relational goals*. Communication Education, 62*(2), 105-126.

Jordan, M. E. & McDaniel, R. R. (in press). Managing uncertainty during collaborative problem solving in elementary school teams: The role of peer influence in robotics engineering activity. *Journal of the Learning Sciences*.

Kafai, Y. B., & Ching, C. C. (2004). Children as instructional designers: Apprenticing, questioning, and evaluating in the Learning Science by Design project. In N. M. Seel & S. Dijkstra (Eds.), *Curriculum, plans and processes of instructional design* (pp. 115-130). Mahwah, NJ: Lawrence Erlbaum.

Kafai, Y. B., Fields, D. A., & Burke, W. Q. (2010). Entering the clubhouse: Case studies of young programmers joining the online Scratch communities. *Journal of Organizational and End-User Computing, 22*(2), 21-35.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., & Holbrook, J. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning-by-design into practice. *Journal of the Learning Sciences, 12*(4), 495-547.

Laursen, S., Liston, C., Thiry, H., & Graf, J. (2007). What good is a scientist in the classroom? *CBE-Life Sciences Education, 6*(1), 49-64.

National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: The National Academies Press.

Otto, K. N. & Wood, K. L. (2000). *Product design techniques in reverse engineering and new product development.* Upper Saddle River, NJ: Prentice Hall.

Pendleton-Julian, A. & Brown, J. S. (2011). *Design unbound: Evolving deign literacy pathways of efficacy*. Draft manuscript, Charleston, SC.

Papert, S. (1980). *Mindstorms: children, computers, and powerful ideas*. New York: Basic Books.

Rogoff, B. (1990). *Apprenticeship in thinking.* New York: Oxford University Press.

Roth, W.-M. (1995). Inventors, copycats, and everyone else: The emergence of shared resources and practices as defining aspects of classroom communities. *Science Education, 79*, 475-502.

Sawyer, K. (2012). Learning how to create: Toward a learning sciences of art and design. *Proceedings of the International Conference of the Learning Sciences* (pp. 33-40). Sydney, Australia.

Shaffer, D. W. (2003). *Portrait of the Oxford design studio: An ethnography of design pedagogy* (Working paper No. 2003-11). Madison, WI: Wisconsin Center for Education Research.

Uluoglu, B. (2000). Design knowledge communicated in studio critiques. *Design Studies, 21*(1), 33-58.