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Exploring How Design Critique Processes Shape Fifth Graders' Peer Interaction in Collaborative Engineering Projects

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The purpose of this naturalistic qualitative study is to explore how public design critique processes shaped fifth grade students' peer interaction during collaborative work sessions. Understanding social processes through which young students learn to engage in collaborative engineering design projects is critical as engineering standards become prevalent in K-12 curriculums. The Next Generation Science Standards (NGSS) require that students not only understand core concepts and cross-cutting ideas associated with engineering, but also learn to participate in engineering practices.[1-3] According to the NGSS, engineering practices are highly social, requiring collaboration and communication with diverse people for multiple purposes. Although it is well-known that communication plays critical roles in the design process[4, 5], systematic studies of children's peer-to-peer interaction during collaborative design activity are rare (but see [6-11]). Furthermore, engineering design requires the ability to communicate with people outside the design team[5], but few studies consider the influence of the broader social context on peer collaboration (but see[12]).

In the robotic engineering design projects observed in this study, students learned by addressing authentic real-world problems in collaboration with their peers. Group members grappled together with the complex issues associated with the design process. The teacher guided students' interactions with each other, with materials, and with concepts through whole-group instruction and when circulating among groups during group-work sessions. She used many scaffolding tools in these efforts, structuring student engagement through individual design journals, product design worksheets, and individual reflection questions. She also instigated classroom talk structures to facilitate learning through peer interaction in small-group and whole-class settings. These included structures such as group wikis[7]; five-minutes "stop-and-talks", and – most importantly for this paper – *public design critique sessions* in which each group presented their progress and received feedback from their teacher and classmates.

Design critique sessions, also called *design briefs*, are one avenue through which the broader social context can exert influence on group-work processes of young designers. Design critique sessions provide opportunities for teams to formally present in-process design plans and garner formative feedback about ongoing design projects.[13-15] Design critiques draw attention to efficient and usable solutions and inconsistencies in a design and facilitate the exchange of knowledge and perspectives related to specifications and procedural aspects of design.[14] Engineering design teams commonly participate in such social events, yet little research examines the influence of design critique sessions on interaction in collaborative design teams and no such studies exist for K-12 settings. This qualitative study attempts to address this gap using a naturalistic, interpretive lens to explore how feedback received in public design critique sessions shaped subsequent group discourse and experience.

For professional engineering design teams, the purpose of public design critiques is to improve design products - achievement of a successful project. In K-12 engineering contexts, improving product design is a sub-goal of activity; the primary goal of activity is to promote learning. Thus, public design critiques need to serve learning goals. Design is a complex process, encompassing multiple iterations of complicated processes requiring many skills and much knowledge. Young adolescents learning to design often struggle with understanding the problem, gathering information, generating solutions, designing and running experiments, reasoning through design issues, evaluating constraints and tradeoffs, communicating difficulties, and applying information from feedback in subsequent iterations of a project. Learning in such complex contexts includes not only coming to understand complicated concepts and participate in complicated practices, but also learning to manage uncertainty associated with open-ended endeavors, novel environments, and collaborative creative problem solving.[6, 8, 9, 16, 17] Thus, engineering design projects present rich learning opportunities. However, students do not always learn as much from hands-on activities as educators might hope.[18-19] Creating effective teaching-learning environments that promote learning from design experiences requires attention to multiple aspects of these complex projects.

Young students need multiple forms of support, including explicit teacher guidance, in order to learn from design activities.[20-21] From the perspective of socioconstructivist theories of learning, support or "scaffolding" often comes in the form of social interaction with "more knowledgeable others."[22-25] In a learning-to-design context, public design critique sessions can play important scaffolding roles by interjecting important features of scaffolded instruction. For instance, design critiques can facilitate intersubjectivity about the goals of project activities, support a teacher's ongoing assessment about students' knowledge, understanding, and skills so that she or he can provide graduated assistance[20], maintain direction, highlight critical task features, control frustration, and demonstrate solution paths[21], and enable substantive dialogue through which teacher and students can negotiate common understandings.[26-28] Because students do not necessarily notice important characteristics of a situation from a teacher's perspective, public design critiques can facilitate guided reflection when iterated with hands-on collaborative activity, reflection that encourages deliberate practice.

If one defines learning as a relatively long-term change, then the "residue" of social interaction – including social interaction that occurs during public design critique experiences - needs to carry over from immediate experiences to future experiences. For instance, if learning from interaction during design critiques has occurred, we would hope to see that something about subsequent collaborative interaction would be different from previous interaction. Through multiple design iterations of their curriculum, *Learning by Design*, Kolodner and colleagues found that learning outcomes improved when time was intentionally allocated for multiple presentations and whole-class discussions of design goals and practices.[20, 29-31] Important for the current study is that *Learning by Design* students showed significant differences from non-LBD students in collaboration and metacognitive skills.[20] While these results support the efficacy of such social interactions, it is unclear how such instructional activities shaped subsequent peer interaction that supported these positive outcomes.

Method

The study drew on data from a longitudinal investigation of fifth graders engaged in designing, building, and programming robots using LEGO Mindstorms building and programming materials (see http://www.lego.com/en-us/mindstorms/?domainredir=mindstorms.lego.com). Naturalistic observational data were collected in a regular public fifth-grade class in a school in the southwestern US. The 24 student-members were diverse in ethnicity, gender, and academic achievement. This was not a special engineering class; only one student had prior robotic engineering experience. The classroom teacher, Ms. W., was well-respected in her school and district for her expertise in engineering education and facilitation of collaborative learning projects. Engineering instruction was well-integrated into the life of this class. Students engaged in three collaborative engineering projects across the school year, changing membership for each project based on the teacher's evaluation of who would work well together. Each project took place in sessions across 14 days and ended with a culminating class-wide or school-wide public event. The first two projects were relatively well-defined problems for which Ms. W. introduced students to tools and practices of robotics engineering, identified the pre-specified objectives and paths for completion common to all groups (e.g., build a pre-designed rover to maneuver through an obstacle course, use an ultrasonic sensor to detect a wall, and reverse direction to land on an X). The final project was an ill-structured design task [32, 33] in which the students were largely responsible for charting their own course through a self-defined goal.

Data for this study was limited to the final project. For this project, students were assigned to one of six four-member groups and tasked to design, build, and program a robot to address an environmental problem they themselves identified. In order to allow for in-depth discourse analysis, two focal groups were selected for exploratory analysis in comparative case studies. Each group was comprised of four members diverse in gender, ethnicity, and academic achievement. These two groups were purposefully selected based on the feedback they received during the design critique sessions: The Water Washer group received primarily negative critique, while the Recycling Rover group received primarily positive critique (See Table 1).

Table 1. Description of Two Focal Groups and Design Activity

Group project	Group composition	Feedback in design critique 1
Water Washer: a paddle-propelled boat operated via touch sensor to clean water pollution	1 girl: Isabel 3 boys: Donte, Peter, Bobby	Primarily negative critique
Recycling Rover: a 4-wheeled vehicle that maneuvers via light sensor to deliver materials	3 girls: Satya, Kisha, Becky 1 boy: Edwin	Primarily positive critique

On Day 1 of the final project, each group brainstormed ideas and made sketches of their initial design ideas for approximately one hour.[8] By the end of Day 1, both focal groups had committed to an initial project idea that would become the final product they would showcase fourteen work-days later in a robotics fair for their school community. The final projects for both groups were rated of approximately equal quality by two independent expert judges.[8] Day 2, the focal day for this study, began with Ms. W. instructing groups to finish their brainstorming. She presented two communication tools to scaffold students' brainstorming interactions: a product information sheet and graph paper for sketching their initial designs. An important aspect of the teacher's instructions was her communication that managing uncertainty and expecting change were inherent aspects of design activity – even for professional engineers. She explicitly indicated that each group's end product would not look like their initial design idea; rather, they should think of their first sketches and product descriptions as their "starting point."

Following the teacher's instructions, the morning group-work session lasted approximately one hour. During this time, the Water Washer group and the Recycling Rover group continued to develop and refine the design ideas and sketches they had begun the day prior, and both filled out their product information sheet. Near the end of this session, the researcher briefly met with both focal groups, informally interviewing them about their perceptions of the group's progress. Mid-day, students participated in the first design critique sessions of the year. The teacher called each group to the front of the room where they projected their most recent design sketch on the Smartboard. Students presented their engineering projects-in-progress and received formative feedback from their teacher and classmates. Subsequent to the design critiques, the teacher instructed all groups to spend ten minutes reflecting with their group members about where they were in their design process and what would be their next steps. As group members talked, the teacher wrote two reflection questions on the board: (1) How has your thinking about your design changed and why?, and (2) What is frustrating you and how are you dealing with it? Students recorded their individual responses in their design journals.

Multiple sources of data were used to understand how peer interaction during collaborative engineering design work was influenced by public design critique processes. Sources were associated with three distinct activity structures and include: (a) transcripts made from video-audio recordings of whole-class design critiques, (b) transcripts of group-work sessions for the two focal groups prior and subsequent to the design critiques, (c) transcripts of whole-group informal interviews with each focal group following the morning work session, and (d) written reflections from all members of the two focal groups at the end of the work day.

Data analysis was inductive and interpretive [34, 35], relying on qualitative discourse analysis informed by sociolinguistics and sociocultural commitments [36-39], including content analysis and the immediate details of talk as they relate to experiencing and managing uncertainty and negotiating meaning of design processes. The researcher examined pre and post design critique session peer-to-peer talk, specifically group members' (a) expressions of uncertainty (e.g., questions, hedges), (b) generation of design ideas (e.g., how many, who made them), and (c) sustained substantive discourse (operationalized in terms of length of topical threads). Transcripts were also examined to identify changes in interactional patterns for each group subsequent to design critique sessions.

Findings

In this section, the feedback the group received during their first public design critique session is described, followed by a description of group interaction patterns prior and subsequent to the design critique as well as interpretation of the influence of critique processes on group discourse.

Nature of critique for the Water Washer group. During the first public design critique, the Water Washer group received one of the highest number of negative critiques and challenges from their teacher, who evaluated the purpose of their product (to heat and cool a swimming pool and clean pool debris) as not meeting the design specification to address an environmental problem ("I have a real issue with what you're doing with the environment. I want you to work on this some more."). Ms. W. also challenged the group on the novelty of the product ("How is this new?"). Finally, the teacher expressed concern that their initial design was under specified in terms of exactly how the product would work, pressing the group several times about particular mechanisms (e.g., "How will you make that? How would the NXT be used?") and reminding the entire class that their products "actually have to work" within the design constraints of available materials. Mixed in with the teacher's largely negative critique were expressions of admiration for the general design concept and for a safety feature of shaping product like an octopus so that "little kids won't mess with it." Ms. W. also helped the Water Washer group troubleshoot the heating element issue when discussion of this design problem this was instigated by a group member. She encouraged the group members to research competing products to "find out what's already out there." Perhaps taking their cues from their teacher, members of the class challenged the Water Washer group to elaborate on the mechanisms ("What's it run on?" "Won't it just get cold?"). They also suggested solutions to address issues of heating elements and propulsion and presented potential arguments to support the environmental importance of the product (i.e., mosquitos lay eggs in dirty stagnant water).

During the design critique, the three boys in the Water Washer group (Isabel was absent for this portion of the day) clarified and defended their design ideas in response to challenges from their teacher and classmates, and expanded on mechanisms (albeit in rather vague terms) in response to questions from their classmates. Interestingly, much of their response seemed spontaneous and did not reference the group's previous discussion. These students did not seem nonplused by the negative critique they received. They began discussing ideas among themselves as they headed back to their desks.

Changes in peer interaction for Water Washer group. Prior to their design critique, peer interaction in this group was marked by overlapping speech and overlapping topical initiations. Topics of a social nature frequently interleaved with topics centrally focused on task issues. Topics protesting off-task talk and initiating task focus were initiated and taken up several times.

One such topic initiation instigated contention about who was and who should be the project manager. Uncertainty about social-relational issues was further exhibited in frequent expressions of uncertainty related to whether a particular course of action was permissible (e.g., "Can I draw that?"). Task-related topics were frequently initiated based on a group member's uncertainty about whether the current design was sufficient (e.g., "I just don't think that heater/cooler thing will work" "How are we going to make faces?"), and these initiations provided opportunities for the group to brainstorm new or elaborated solutions (e.g., "I don't remember what it's called, but you put this plasticy stuff [saran wrap] on it, just in case it gets wet it doesn't ruin." "I get the cooler thing. We have the jar with all this ice in it and it just opens."). However, because multiple topics were frequently juxtaposed, it seemed difficult for this group to sustain focused attention needed to improve elements of their design. In their 375 comments in this session, only 12 (3%) expressed new design ideas not previously discussed by the group.

Despite these difficulties, members of the Water Washer group appeared relatively free of worry about the quality of their product prior to the design critique. Near the end of the morning group-work session, the group was informally interviewed by the researcher. In response to her question, "How's it going?", Donte replied, "Excellent-e!" and Isabel, "It's going good." When asked if they had experienced any challenges, Isabel reported, "No, not really." Donte also responded in the negative. However, Bobby was more cautious, re-joining, "Cause we're not building yet…The building's going to be a lot harder." This was possibly an admittance that the group was not as clear as Bobby felt they needed to be about how their product would work. It also may have been due in part to his appropriation of Ms. W.'s warning to expect that their product would change. However, none of Bobby's group members elaborated or seemed to share his uncertainty. Also noteworthy is that Isabel took the opportunity to broach a subject that was becoming contentious – who was project manager – perhaps bringing it up in front of an adult for a measure of safety in addressing a relational difficulty.

As to how the feedback they received during the first design critique session shaped this group's social interaction, findings indicate a decrease in students' focus on social-relational issues as members became more task-focused after receiving negative feedback. No social topics were taken up post critique. Sustained substantive discourse increased post-critique. Although topics continued to be interleaved, they were all task focused topics and this interleaving now seemed used to elaborate on previous topics that a group members perceived as needing more discussion. Additionally, two post-critique topics of discussion focused on evaluating to what extent group members were "on the same page", an element of discourse not present in the group's pre-critique session. The number of design ideas proportional to total talk turns increased (total of 22 new design ideas in 157 comments; 14%) as group members re-invested in brainstorming using new perspectives forwarded during the design critique session.

The group particularly seemed to go back to the drawing board in terms of understanding design specifications and product function. Much of their desire to gain this understanding seemed driven by a desire to keep their product the same by "stick[ing] with the swimming pool" and trying to “prove Ms. W. wrong.” Much of their post-critique discussion focused on the function of their robot, building on an idea suggested by one of their classmates during the design critique. Thus, even though the negative feedback spurred resistance to change, the group’s talk - spurred by the resistance - was filled with elaboration, justification, and sustained co-construction of productive argumentation. Previous contention related to social-relational issues and group leadership was not broached subsequent to the design critique session, as group members turned their attention to task-related topics.

Reluctance to change their initial design plan or generate uncertainty about their initial design ideas was also reflected in members’ responses to the written reflection questions assigned by the teacher at the end of Day 2. The three boys were particularly resistant to admitting change. Peter reported that they had decided to “keep it the same; just it can go in many different places.” Donte was more specific about the change, writing, “It can pik [sic] up the pool or the river to help keep pool hot or cold and clean your community creek.” Isabel was the only member to explicitly admit to changing the design: “We changed our design to go in a river and a pool. It could pick up trash in a river but it could relacks [sic] your pool.” All four members of the Water Washer group reported experiencing frustration, though about different things. Bobby reported, “What's frustrating is the thing we made might be created already, so all we have to do is look it up and make sure it's not real.” Peter was frustrated by both task and social/relational issues “how to agree and make it work right.” Isabel added an additional metacognitive note, “I am frustrating about that we cannot just put it in a pool. I am handling it pretty good. We just rethought about it.” Thus, post critique, these students’ talk and writing exhibited increased metacognitive reflection on evaluating group product and process.

Nature of critique in the Recycling Rover group. During the first public design critique, the Recycling Rover group received one of the highest number of positive critiques from their teacher. Ms. W. evaluated their self-identified problem as meeting the design specifications to address an environmental problem, evaluated their design solutions as challenging but fitting within the constraints of available materials (“That’s a big task, but I like it.”) and their programming as “definitely doable.” Although she had previously instructed the class not to do trash picker-uppers because they had been “done to death” in previous years, she contrasted the Recycling Rover with past projects and defined it as sufficiently unique. She also gave the group two suggestions related to locomotion, recommending that they program their robot to read different things on one “line sensor” program and that they use a touch sensor to activate different parts of the program. Student-members of the class contributed less to this critique session than to the critique of the Water Washer robot. When prompted by Ms. W., they confirmed that the proposed design did address an environmental problem. The Recycling Rover received only one suggestion from a student-member of the class. Zeke described how they could use three motors to power three separate boxes for different types of trash “instead of putting it in and waiting for it to come back.”

For their part, the group (primarily animated by their leader, Satya) clearly described their product, explaining their detailed sketch, heavily emphasizing the structures but also describing mechanisms (e.g., “the light sensor reads it”). The Recycling Rover group was one of the few to address programming in this first presentation, possibly because they had decided to use a programming strategy that closely matched the program all groups used in the previous project.

Changes in peer interaction for Recycling Rover group. In the group receiving primarily positive feedback (Recycling Rover), uncertainty expressions and generation of design ideas remained equally high pre-and-post critique, as did sustained substantive discourse. Prior to the critique session, group interaction elicited 19 new design ideas in 230 comments (8%); more than in the Water Washer group despite the fact that this group made far fewer comments. Topical threads were of various lengths, some sustained and some easily resolved. Although the tone of group dialogue was friendly and respectful, only one short topic was of a social nature. As in the Water Washer group, uncertainty was expressed frequently in the Recycling Rover group. However, the two groups differed in that expressions of uncertainty in the Recycling Rover group were primarily related to requesting task-related information or seeking confirmation for task-related ideas and understandings. Additionally, several Recycling Rover group members engaged in potentially uncertainty-generating talk by eliciting additional design ideas from their group members.

Near the end of the morning group-work session, the members of the Recycling Rover began clearing up their work station. Much like the Water Washer group, they seemed confident at this point in the efficacy of their design ideas. When the researcher asked how they were feeling about their project, Becky, Satya, and Kisha all reported feeling good. Only Satya elaborated, describing their programming plan, expressing confidence but hedging to show some degree of uncertainty (“most likely” “that’ll probably make it work”). Like members of the Water Washer group, these students reported that they had not experienced any big challenges that day. However, members of this group engaged me in much more conversation related to issues about which they were still uncertainty. Like Bobby from the Water Washer group, Satya expressed uncertainty related to going from design sketches to building, “We really need to start building because it’s kind of hard to progress without knowing what the robot will look like and how we have to change it.” This dovetailed with Satya’s propensity to frequently express uncertainty about future design iterations in her group interactions (“We’ll do this for now, but we might need to change it later.”), planning for the inevitable change about which her teacher had warned. Edwin added uncertainty about whether their product was sufficiently unique, saying “We need to start the research.” All four students expressed uncertainty about materials they would need.

Subsequent to the design critique session, members of the Recycling Rover group remained committed to improving their product. Kisha opened the group’s afternoon work session by suggesting that the group adopt the teacher’s idea to use a touch sensor to trigger their line follower program. She reminded her group members of the function of the touch sensor, and expressing uncertainty, “But then how would we do that?” The group continued to engage in planning for the future, express uncertainty about whether and how ideas expressed in the design critique session would work in ways that prompted other members to create new design solutions (e.g., Kisha: But how would we dump them? Edwin: How about we put multiple arms then, too. And then the lift it up and then they move it across all the other boxes and then they dump it.). That the feedback they received during the design critique was overwhelmingly positive seemed to spur this group to discuss eight new design ideas in 106 comments (8%). Also, two of the group's nine post-critique topics were evaluative of the quality of the group ("We got a good get-along group") and its progress.

Written reflections of Recycling Rover group members at the end of Day 2 confirmed that all members remained cognitively engaged in improving their initial solution ideas. Edwin reported that the group had decided to add a line for recycling plastic "because we forgot that plastic pollutes the earth." Becky reported that she was thinking calmly instead of focusing on something "fancy and nice looking," while Kisha puzzled over an improvement to propulsion, using a touch sensor "so all you have to do is tap it." There was less report of frustration by members of the Recycling Rover group than by the Water Washer group. All members reported that they were not frustrated, Kisha because she was "pretty sure our design is going to work." Three members added phrases to their reports that showed they were aware that design work can be frustrating, perhaps as a way of preparing themselves for that future experience (e.g., "if we continue I know I will [experience frustration]"). Perhaps their positive affect was encouraged by the positive feedback they received during their design critique, coupled with their acceptance of change as a natural part of the design process and planfulness in addressing it, including their plans to seek help from their teacher for issues about which they were still uncertain.

Discussion

Social interaction with the teacher and classmates during public design critique sessions seemed to shape peer interaction in both the focal groups analyzed for this study. Regardless of whether they received primarily positive or negative feedback during their first design critique, members of the Water Washer and Recycling Rover groups remained committed to improving their engineering product ideas. Both groups made use of ideas suggested in design critique sessions to improve their design solutions and talk about suggestions elicited still more ideas as the group members talked. Interestingly, topics related to social-interactional issues decreased in the Water Washer group subsequent to the design critique, and increased in the Recycling Rover group. It is possible that negative feedback led members of the Water Washer group to increase focus on task issues while members of the Recycling Rover group basked in the positive group feelings that accompanied affirmative feedback. Further research is necessary to test that hypothesis since groups were not randomly assigned to feedback conditions independent of performance in the design of the current study. Furthermore, the design critique sessions examined here took place early in the design process. Responses to negative or positive feedback may differ in later design critiques after students had more time to frame their problem and address their initial design.

Also noteworthy is that members of the Water Washer group seemed far less comfortable with uncertainty and change than members of the Recycling Rover, resisting change rather than embracing it. This reticence was reflected in pre-design critique talk as well as post-design talk. It is possible that the Recycling Rover group may also have resisted changing their product had they received negative critique. However, prior to the public design critique, the members of the Recycling Rover group seemed more aware of uncertainty and more planful than members of the Water Washer group. Their willingness to embrace uncertainty and plan for change prior to the critique, as well as their willingness to continue refining their design ideas based on feedback, suggests that this group had appropriated their teacher's conception of engineering design as an inherently uncertain, dynamic process. This finding could be related to the gender composition of the two focal groups; the Water Washer group was comprised of mostly boys and the Recycling Rover group was comprised mostly of girls. Previous research suggests that females and males may manage and interpret uncertainty differently.[40, 41] Further research is needed to understand the influence of students' stances toward uncertainty and to understand how gender might be a factor in the results of this study.

Outcomes associated with this study contribute to increased knowledge of how broader social interactions influence peer-to-peer discourse in collaborative engineering design projects. The ultimate value of the study is its potential to impact educational thought and action by informing teaching and learning practices related to public critique processes associated with engineering design. Nonetheless, the fact that this descriptive study was limited to analysis discourse in only two groups inhibits generalizability to other groups or contexts. Further study is needed to understand how social feedback from public design critique sessions can facilitate learning. Next steps in this line of inquiry should include following each focal group across the two other design critique sessions that occurred during this design project to describe how the dynamics of group interaction may shift across time. It also will be important to describe how ideas generated during whole-class public design critique sessions were taken up by these two focal groups and their classmates in other groups in subsequent small-group work sessions. Determining this uptake would require examining group products as well as group discourse. Finally, systematic comparison between groups to determine the relative effects of negative and positive feedback received during public design critique sessions would require carefully controlled experimental conditions that were not a part of the current study design.

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