122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13552

Investigating Middle School Students' Perceptions of Communication Challenges in Collaborative Engineering Design Learning (fundamental)

Dr. Michelle E Jordan , Arizona State University

Michelle Jordan earned her PhD in Educational Psychology at the University of Texas at Austin, focusing her studies on learning, cognition, and motivation with an emphasis on classroom discourse. She joined the Mary Lou Fulton Teachers College at Arizona State University in 2010. Her interdisciplinary research draws on traditions in qualitative inquiry, sociolinguistics, complexity theories, and the learning sciences. Partnering with teachers and researchers across multiple contexts, Michelle's research agenda explores the relationships among small-group interactions, the experiences they facilitate, and their potential to extend human learning in diverse contexts including K-12 engineering design teams.

Ms. Mia DeLaRosa

Investigating Middle School Students' Perceptions of Communication Challenges in Collaborative Engineering Design Challenges (Fundamental)

Educators are increasingly interested in engineering education as K-12 engineering standards become more prevalent[1-3] and as benefits of design experiences for science learning gain recognition.[4, 5] Collaborative problem solving around engineering design projects are especially important because they represent the ways professional engineers often work.[6, 7] Drawing on our diverse backgrounds as a highly effective middle-school science teacher, an assistant professor in a teacher preparation program, and a pre-service teacher candidate, we explored the creative collaboration of eighth-graders engaged in engineering design activity. In particular, we were interested in learners' perceptions of their group's communication patterns, and their perceptions of their own participation in their group. Our interest grew out of previous findings indicating that students encounter communication challenges related to task, relational, and identity issues when collaborating on engineering design projects.[8, 9] Even professional designers struggle with these complex issues, frequently encountering misunderstandings, avoidance of conflict, and persuasion to achieve adoption of ideas and actions .[10] Negotiating these social processes is particularly difficult for young adolescents who are still developing the metacognitive capacities required for such negotiation[11] and confronting new relational concerns.

As an ill-structured, generative activity, collaborative designing entails multiple forms and sources of uncertainty.[12-13] Intractable ambiguity associated with creative endeavors, partial knowledge students have about new content, and negotiation of social roles, responsibilities and positions all present communication challenges as students engage in design projects[8]. Moreover, complications abound because the various contingencies are interdependent (e.g., knowledge of content constrains solution options). Effective engineering design learning depends on structuring a predictable environment in which students feel safe to explore and create within bounded constraints. Incorporating classroom structures to facilitate productive peer-to-peer communication is one part of creating such an environment.

Research in learning and motivation presents multiple perspectives for educators and researchers to draw from as they attempt to understand peer communication and develop strategies to support productive peer communication during design challenges. Boekaerts'[14] self-regulation model describes dual processes by which students simultaneously regulate task goals (e.g., increased competence) and social goals (e.g., help others). Understanding these processes requires taking into account the conditions of the learning environment and students' perceptions of that environment. Focusing directly on collaborative learning contexts, scholars have begun investigating processes of co-regulation and socially-shared regulation of learning.[15-17] Barron[18] found effective coordination of problem solving requires joint management of attention to content and relational. Meta-analysis by Chi and colleagues[19, 20] suggest that interactive learning environments are beneficial for learning. However, students may need help developing interacting-learning skills to capitalize on such environments.

A few studies have begun investigating these issues specifically in engineering design contexts with middle-grade students. In a study specifically investigating peer interaction during design challenges, Roth[21-, 22] identified ways in which peers influence one another's design practices during engineering challenges. Author[8] previously found that effectively managing uncertainty is facilitated through communicative processes when peers were willing and able to provide support. Kolodner and colleagues[4, 5] developed ritualized activity structures that facilitate peer interaction. The purpose of the present mixed-methods study was to investigate how middle-school students' respond to communication challenges during a set of design-reflect-design processes associated with collaborative engineering design. Two questions guided analysis:

> RQ1: What do learners' written reflections reveal about their perceptions of their group's communication patterns, and how do these perceptions shift across the two design challenges?
>
> RQ2: What are learners' perceptions of the quality of their individual-level interactions, and how do these perceptions shift across the two design challenges?

Method

The context of this mixed-methods study was three eighth-grade science classes in one Title I urban school (88% of students qualified for free or reduced lunch; 14% were classified as English language learners) in the southwestern U.S. The second author was the teacher of all three classes.

Drawing from previous research on peer-to-peer interactions during collaborative work (See, for example, [8, 9, 21, 22, 23]), we identified two social issues (negotiating roles and responsibilities, evaluating progress) and two task issues (understanding the task specifications, generating design ideas) that present communication challenges for individuals engaged in collaborative design activity: negotiating roles and responsibilities; evaluating task progress and group interaction; understanding the task; and generating new ideas or solutions. These communication challenges became the basis for reflective survey questions, observers' notes, and class debriefings.

Taking a design-based approach[24, 25] in this, our second iteration of these processes, the study protocols occurred over three 50-minute class periods on consecutive days in a design-reflect-design process (i.e., Project #1, reflection on communication patterns, Project #2). The first and second authors were both present for all activities. Students were assigned to one of two roles for the entire process: (a) engineering design-team member in three-to-five member teams, or (b) design-team student-observer. On Day 1, the first author (a researcher at a local university) oriented observers to an observation tool designed and field-tested by the authors, while the teacher oriented design-team members to a simple engineering design challenge. This design challenge provided an opportunity for designers and observers to reflect on communication patterns. Following the 18-minute challenge, the observers compared notes while design-team members completed individual written reflections. On Day 2, designers discussed their group patterns in their teams and then in a whole-class discussion. Afterwards, student observers presented whole-class feedback and made suggestions for improving communication. Day 3 followed a protocol similar to Day 1, but with a different 18-minute challenge. Neither roles nor team-members changed across days except when necessary because of absences.

Data collection included video/audio recordings, field notes, design-team members' responses to five open-ended reflection questions related to group-level communication patterns, and a six-item Heedful Interrelating in Collaborative Experiences Scale (HICES) scored on a seven-point Likert scale. The HICES scale was developed to measure students' perceptions of the quality of their own socio-cognitive actions during collaborative academic projects[26-28] Three video recorders were strategically placed to capture design-group interactions each day. Both surveys were administered to design-team members immediately following each engineering design challenge.

Data analysis for the present study was limited to examination of learners' responses to open-ended questions and HICES scale scores for participants from whom surveys were collected on both Day 1 and Day 3 (N=68; 35 female, 33 male; 50 Hispanic, 18 other). Analysis of open-ended questions was iterative and interpretive. We used constant comparative methods, open and axial coding, and iterative cycles of independent memoing/coding. Codes and themes were negotiated among research team members at weekly meetings.[29] We first created an excel document of all survey responses, de-identifying and randomizing them before analysis to reduce potential bias. Open-coding commenced with all authors independently reading vertically across learners' responses to the five survey questions, noting patterns and making extensive memos. There followed a team meeting to distinguish patterns within and across participants and tentatively identifying initial themes. Subsequent team meetings utilized much discussion and sketching of distinctions and similarities within and between participants.

Multiple iterations of these axial coding processes yielded sub-models of RQ1: learners' perceptions of their group's communication patterns. Using these models as the basis for analysis, all responses to the first four survey questions were coded and frequency of codes tallied to further address RQ1. Finally, a t-test was conducted to compare HICES scores for Day 1 and Day 3 in order to address RQ2.

Results

In regards to RQ1, several trends emerged from analysis of the open-ended questions regarding students' perceptions of their group's communication patterns during engineering design challenges and changes in those perceptions across the two projects. In turn, we discuss students' reports of how their group navigated four communication challenges associated with collaborative design activity: negotiating roles and responsibilities, evaluating progress, understanding the task specifications, and generating design ideas.

Figure 1 shows the distribution of responses across the five codes we identified for students' responses to the question "How did your team negotiate the tasks each person would do?". These codes further clustered into two categories: responses focused on task-related issues and responses focused on interpersonal issues. More specifically, many students focused on roles, whether their group had them and how they emerged, while others focused on the interactional quality of design team communication. Of the group focusing on roles, some reported that their group assigned roles – either through delegation or self-selection (N = 10 on Day 1; N = 15 on Day 3). In contrast, others reported that roles emerging when needed as the task unfolded (N = 12 on Day 1; N = 8 on Day 3). An equal amount of students reported that their group did not assign roles and often remarked that they "just did it" (N = 17 on Day 1 and Day 3). Finally, some students reported on interpersonal issues related to negotiating tasks only, not mentioning their design structure at all and not distinguishing among participants in terms of roles or responsibilities (N = 19 on Day 1; N = 25 on Day 3). [Note: total Ns do not sum to 68 here or in analyses below because some responses were missing or uninterpretable.]

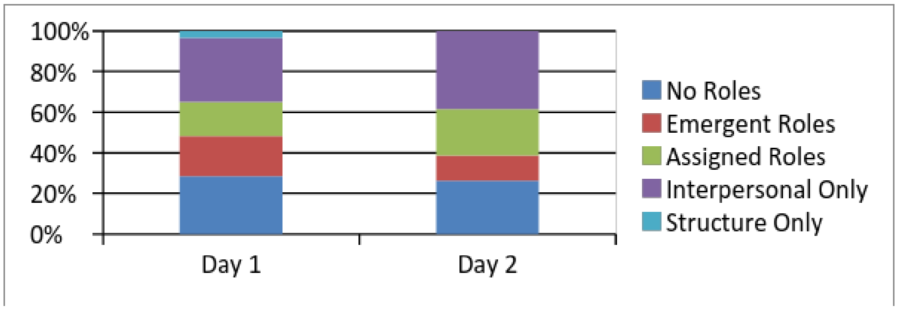

Figure 1. Students' Perceptions of How Their Group Negotiated Tasks

In short, the majority of students attended to the extent to which roles and responsibilities were delegated (or not) across both design challenges, although the proportion of students who focused purely on interpersonal issues increased on Day 3. Additionally, fewer students reported that no roles existed in their group on Day 3, which may indicate their growing awareness of how individuals differentiate themselves and their responsibilities during collaborative design.

We interpreted students' responses to this question as existing on a continuum between exhibiting focus on the built structure as a driver of activity and goals, and a focus on people and their interactions as the driver of activity and goals. We interpreted the assignment of roles at the beginning of the design challenge as a focus on people, perhaps indicating a felt need to organize socio-interactional work, and the emergence of roles as a focus on structure, perhaps indicating that the design goals were paramount for a responder. Thus, across time, students seemed to shift attention to socio-interactional over task issues.

Learners also offered a range of perceptions of how their team *evaluated their progress*. Figure 2 shows the distribution of responses across the seven codes we identified for students' responses to this question.

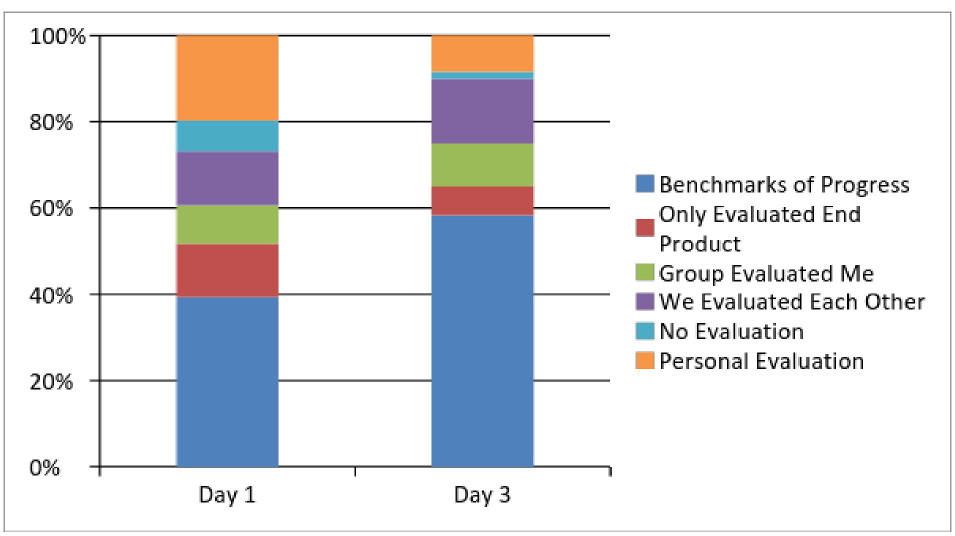

Figure 2. Students' Self-Reported Perceptions of How Their Group Evaluated Progress

These codes clustered into three categories identified through iterative rounds of interpretive coding. Specifically, students reported that their team primarily evaluated the tangible design structure itself (N=29 on Day1; N=39 on Day 3), keyed into emotional-relational qualities of interactional evaluations (N = 12 on Day 1; N = 15 on Day 3), or reported that no evaluation took place in their group (N = 4 on Day 1; N = 1 on Day 3). Of students who reported evaluating the design structure, most described using tactics such as keeping track of the time, working in sequential steps, or checking to see how other teams were doing as benchmarks to evaluate their task progress (N = 22 for Day 1; N = 35 for Day 3). These responses varied by the time interval students used to measure progress (ongoing work vs. end product). Sometimes, students' written language included time indicators such as "every few minutes" and "right away." They also broke the project into steps or parts (e.g., "we worked on the base and then on the tower"). This set of respondents grounded their design in related examples. Their reflections evidenced that they looked at other teams, referred back to the first challenge, or contemplated real-world structures with which they were familiar such as a pyramid or the Eiffel Tower. Some learners in this set focused only on the end product rather than the benchmarks (N = 7 on Day 1; N = 4 on Day 3). This was exhibited in responses like, "we tried but failed." Student who focused on emotional-relational issues related to evaluation wrote about their perceptions of evaluating progress by focusing on the relationships they had with their teammates. Some learners noticed how the team evaluated them as individuals (N = 5 on Day 1; N = 6 on Day 3); others focused on their perceptions of how team-members evaluated each other (N = 7 on Day 1; N = 9 on Day 3).

Across the two engineering design challenges, the proportion of responses indicating that students attended to benchmarks of product success increased and the proportion of responses indicating that students only evaluated the end product decreased, as did reports that evaluation did not occur. Note also that students' misinterpretation of the survey question as asking for their own personal evaluation of ideas, the group, or the product also decreased.

Analysis identified five ways learners communicated to *understand the task*. Figure 3 shows the distribution of coding for students' self-report of these five strategies. Participants reported reading the instructions (N=18 on Day 1; N = 36 on Day 3), asking questions (N=23 in Day 1; N = 26 on Day 3), listening (N=2 on Day 1 and Day 3), and observing other teams (N=1 on Day 1 and Day 3). Four students reported not engaging in strategies to understand the task on Day 1, compared to 1 on Day 3. Each of these strategies for understanding the task revealed either an internal or external focus. Learners sometimes wrote about understanding the task as a sequence, first trying to gain clarity within their team, then moving outward beyond the group if they needed more assistance. For example, learners reported reading and re-reading the task instructions either to themselves or aloud to their teammates, or asking questions to their team and then to the teacher. A higher proportion of students reported reading the instructions to understand the task on Day 3 as compared to Day 1; reading and questioning remained the most used strategies.

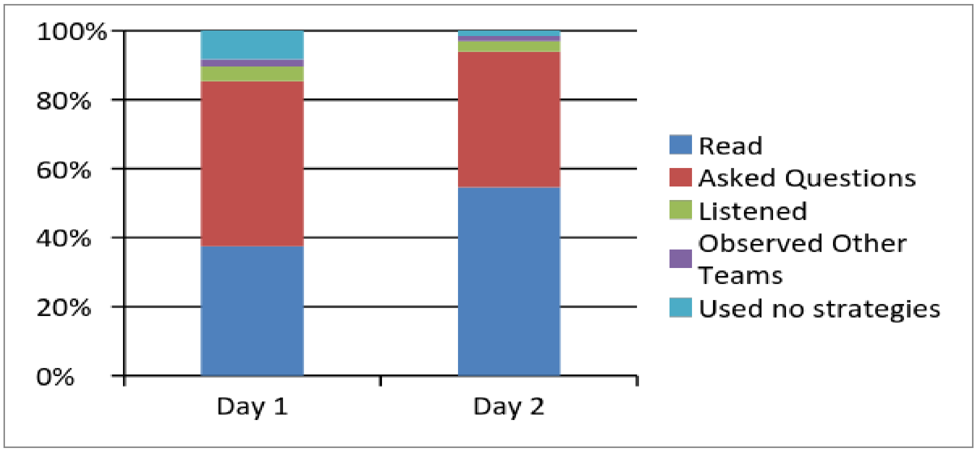

Figure 3. Students' Self-Reported Strategies for Understanding the Task

Learners' perceptions of how their team *generated new ideas/solutions* seemed to exist on a continuum from a simple exchange with little discussion of ideas to increasingly complex communication. Figure 4 shows some students reported sharing ideas, but did not elaborate on the quality of that sharing (N = 34 on Day 1; N = 32 on Day 3). At a slightly higher level of sophisticated communication, students reported that they questioned, explained, critiqued, or otherwise evaluated each other's ideas in order to check or increase their understanding of their classmates solutions (N = 10 on Day 1; N = 16 on Day 3). Finally, in what we interpreted as the highest level of sophistication, some students reported building on each other's ideas by extending and elaborating on their teammates' ideas (N = 10 on Day 1; N = 6 on Day 3). A small proportion of students reported that their group did not generate new ideas (N = 6 on Day 1; N = 2 on Day 3).

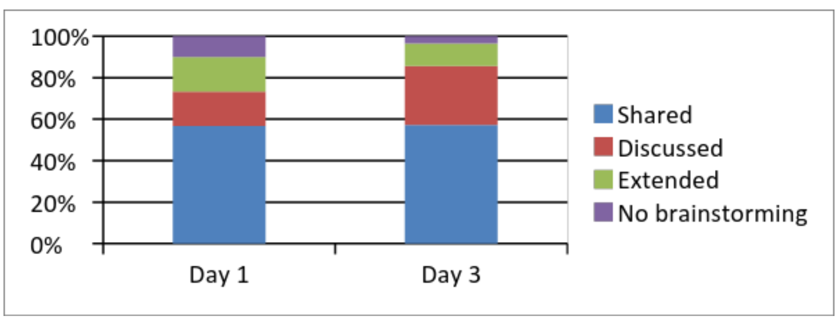

Figure 4. Students' Self-Reports of How Their Group Brainstormed New Ideas

Another distinction we identified in students' responses to this question was whether they reported that the processes of deciding on a solution was accomplished by selecting the best alternative (N = 8 on Day 1; N = 8 on Day 3) or through a process of discussing and then combining ideas (N = 5 on Day 1; N = 7 on Day 3). We also noted students' responses to this open-ended question often indicated *why* they brainstormed ideas together (i.e., the purpose), citing one of three reasons: (a) to hear everyone's voice, (b) to create the best product possible, or (c) to respond to a problem, crisis, or malfunction. Learners sometimes added perceptions of *when* they brainstormed, conveying distinct variations in the perceived tempo at which brainstorming occurred by either using words indicating a time interval (e.g., beginning, middle, end, never) or writing about frequency of brainstorming activity.

In regards to RQ2, students' responses to the HICES scale indicated that learners' self-perceived quality of their own interactions with teammates was moderately high (Day 1: M=4.99, sd =1.14; Day 3: M=5.00, sd =1.09). No significant difference was found between the two engineering challenges.

Discussion

Participants in this study revealed a variety of perceptions about how their teams navigated the complex communication challenges associated with collaborative engineering design activities. Teams had differential ways of negotiating tasks, evaluating their progress, understanding the task, and generating design ideas. They also varied in the extent to which they focused on social-interactional issues versus task-related issues. Furthermore, responses to the open-ended survey questions revealed shifts in how students attended to group-level interaction patterns associated with all four communication challenges. Looking across the open-ended questions, it appears that interpersonal issues may have increased as an issue of concern or attention across the two projects as students attended more to socio-interactional issues in their written responses to Project 3. This could be because we were directing their attention to these issues, or it could be because with experience they increasingly recognized the communication challenges associated with collaborative design processes. Furthermore, it appears that students felt that their group took more socially-responsive actions during Project 3; for instance, more learners reported intentionally delegating roles rather than letting roles emerge. There was a corresponding increase in learners' focus on evaluating their design structure with more intentionality (i.e., using benchmarks) and in using available resources to understand their task (i.e., reading instructions). Fewer respondents reported not engaging in all four communicative activities, which may mean they were more aware of doing do. Thus, it seems that these middle school learners were increasingly able to articulate responsivity to communication challenges related to task and social-interactional issues. We interpreted the shifts across the two design projects as indicating that these middle school learners may have grown in their metacognitive awareness of their groups' communication patterns across the engineering design-reflect-design procedures. These metacommunicative shifts may be reflective of actual group process changes; however, analysis of observational data is necessary to confirm this hypothesis.

There was little shift in students' reports of brainstorming activity across the two projects. Although more responses were coded as discussing ideas during Project 3, fewer responses were coded as extending ideas, and similar proportions of learners reported simply sharing ideas as in Project 1. This may be of concern as building on newly generated ideas is a central activity in engineering design and a key benefit of collaboration. Furthermore, despite changes in students' reported perceptions of group-level interactional patterns, their responses to the HICES items did not reveal a corresponding change in their perceptions of the quality of their individual-level interactions. Although the mean score of 4.99 from Day 1 indicates a fairly high self-perception, the seven-point scale indicates that most students felt that they had room for improvement. Yet, the mean of 5.00 from Day 3 indicates that they did not feel they had made such improvement. That analysis revealed changes in how students perceived their group but not how they saw themselves may be an artifact of the different methods we used to probe these perceptions. However, it may also indicate that metacognitive awareness of group-level interaction is easier for middle school students to develop than metacognitive awareness of their own individual actions. If so, facilitators may need to capitalize on learners' group-level assessment while providing increased support for reflection on self as collaborator.

Implications

The findings of this study are significant in that understanding student perceptions of their communication patterns may help educators and learning scientists design strategies to improve peer-to-peer communication and enhance design learning in engineering and science learning contexts. Productive collaboration does not just happen, and efforts to help students learn from group work do not always yield hoped-for results.[18, 30] Middle-school students need a great deal of scaffolding and practice developing their collaboration skills since perspective taking and understanding diversity are not innate capabilities. Effective collaborative communication in engineering design is a skill set that needs to be modeled, taught, and practiced over time. The variation in students' reported perceptions of how their team navigated communication challenges suggests that learners may benefit from scaffolding of social-interactional issues associated with collaborative design. Support may come, for instance, in facilitators explicitly inviting teams to structure their collaborative interaction and use the structure for each iteration of problem solving (e.g., one student at a time shares his/her ideas without feedback or interruptions). Facilitators may need to model processes for enhancing collaborative brainstorming by probing for understanding and elaborating on team members' ideas or by eliciting responses about one's own ideas.

The study also has implications for helping students navigate particular communication challenges. For instance, when students reported on how their team negotiated tasks, some focused on the task at hand, while others focused on the interpersonal aspect of their experience. Facilitators should recognize these two dichotomous perspectives are at play, validate both as being important (rather than favoring one over the other), and encourage discussion to increase social metacognition and students' ability to effectively communicate their preferences, strengths, and needs. Those students who are more concerned with the task could be given roles such as timekeeper, spec checker, or internal evaluator. Others who are interested in the interpersonal aspects could take on roles of communication facilitator, team celebration captain, or mediator. Inviting students to metacognitively assess their own viewpoints then selecting roles to enhance that may be one way to increase overt participation in an engineering design challenge setting. To further scaffold, facilitators might provide design-teams with a list of proposed roles to choose from. However, in design settings, it may be important for students to self-select the roles they take on during an open-ended design challenge.

Future analysis will compare students' perceptions with student-observers' and researcher/teachers' perceptions based on recorded data and transcripts of design-team interaction. It will also compare these perceptions with project outcomes. Furthermore, a third design iteration is planned using revised protocols and instruments based on the results of this study. For instance, for the question about how groups' evaluated their progress, a total of 20 responses could not be coded or were missing a response altogether, and an additional 16 responders reported their own evaluation of ideas, the group, or their product, rather than describing group processes for evaluation. This suggests that improvements are needed in study instruments.

References

1. National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.
2. National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. Washington, DC: The National Academies Press.
3. Carr, R. L., Bennett, L. D., & Strobel, J. (2012). Engineering in the K-12 STEM standards of the 50 U.S. states: An analysis of presence and extent. *JEE, 101*, 539-564.
4. Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., Puntembakar, S, Ryan, M. (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 - 548.
5. Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., & Ryan, M. (2004). Promoting deep science learning through case-based reasoning: Rituals and practices in learning by design classrooms. In Seel, N.M. and Dykstra, S. (Eds.), *Curriculum, plans and processes of instructional design: International perspectives*. Lawrence Erlbaum Associates: Mahwah, NJ.
6. Brereton, M. F., Cannon, D. M., Mabogunje, A., & Leifer, L. J. (1996). Collaboration in design teams: How social interaction shapes the product. In N. G. Cross, H. H. C. M. Christiaans & K. Dorst (Eds.), *Analysing design activity* (pp. 319-341). Chichester: Wiley.
7. 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.
8. 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. doi: 10.1080/03634523.2013.769612
9. Jordan, M. E. & McDaniel, R. (2014). Managing uncertainty during collaborative problem solving in elementary school teams: The role of peer influence in robotics engineering activity. *Journal of the Learning Sciences, 23*(4), 490-536. doi:10.1080/10508406.2014.896254
10. Cross, N., & Cross, A. C. (1998). Expertise in engineering design. *Research in Engineering Design, 10*(3), 141-149.
11. Keating, D. P. (2004). Cognitive and brain development. In R. M. Lerner (Ed.), H*andbook of adolescent psychology* (pp. 4584). New York, NY: John Wiley & Sons.
12. Jonassen, D. H. (2000). Towards a design theory of problem solving. Educational Technology, Research and Development, 48(4), 63-85.
13. Metz, K. (2004). Children's' understanding of scientific inquiry: Their conceptualizations of uncertainty in investigations of their own design. Cognition and Instruction, 22(2), 219-290.
14. Beokaerts, M. (2009). Goal directed behavior in the classroom. In K. Wentzel & A. Wigfield (Eds.), *Handbook of motivation at school* (pp. 105-122). New York and London: Routledge.
15. Hadwin, A. & Oshige, M. (2011). Self-regulation, coregulation, and socially shared regulation: Exploring perspectives of social in self-regulated learning theory. *Teachers College Record, 113*(2), 240–264.
16. Jarvela, S. & Volet, S. (2004). Motivation in real-life, dynamic, and interactive learning environments: Stretching constructs and methodologies. *European Psychologist, 9*(4), 193-197.
17. Jarvela, S. & Jarvenoja, H. (2011). Socially constructed self-regulated learning and motivation regulation in collaborative learning groups. *Teachers College Record*, 113(2), 350-374.
18. Barron, B. (2003). When smart groups fail. *Journal of the Learning Sciences, 12*(3), 307-359.
19. Chi, M.T.H. (2013). Learning from observing an experts' demonstrations, explanations, and dialogues. In J.J. Staszewski (Ed.), *Expertise and skill acquisition: The impact of William G. Chase, (pp. 1-28)*. New York: Psychology Press.
20. Chi, M. T. H. & Wylie, R. (2015). ICAP: A hypothesis of differentiated learning effectiveness for four modes of engagement activities. *Educational Psychologist*, 49(4), 219-243.
21. 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.

22. Roth, W.-M. (2004). Art and artifact of children's designing: A situated cognition perspective. *Journal of the Learning Sciences*, 5(2), 129-166.
23. Radinsky, J. (2008). Student's roles in group-work with visual data: A site of science learning. *Cognition and Instruction*, *26*, 145-194.
24. Anderson, T., Shattuck, J. (2012). Design-Based Research: A decade of progress in education research. *Educational Researcher, 41*(1), 16-25. http://edr.sagepub.com/content/41/1/16
25. Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences*, *2*(2), 141-178.
26. Jordan, M. E. (2010). Collaborative robotics design projects: Managing uncertainty in multimodal literacy practice. *Yearbook of the National Reading Conference*, *59*, 260-275.
27. Jordan, M. E. (2015). Variation in students' propensities for managing uncertainty: A study of fifth graders engaged in collaborative academic tasks. *Learning and Individual Differences*, *38*, 99-106. doi:10.1016/j.lindif.2015.01.005
28. Jordan, M. E. (under review). *Discursive shifts in public design critique sessions associated with fifth graders' collaborative engineering projects.*
29. Corbin, J. M. & Strauss, A. L. (2008). *Basics of qualitative research.* UK: Sage.
30. 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.*