Learning and Becoming in Design Reviews

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Abstract: *Drawing from the prior work of McNair and Paretti (2010), this study investigates how language practices and design artifacts mediate the interactions among novice and expert designers to shape the nature of design, and specifically design learning. By analyzing data collected from two design courses in different fields, this study addresses two research questions: 1) how do language practices mediate the interactions between design mentors and design learners; and 2) how do design artifacts mediate these interactions between mentors and learners? Drawing on activity theory and discourse analysis, we use these questions to explore how students work with experts to make meaning within their design experiences. In doing so, we treat meaning-making as an array of social processes situated within a complex activity system that includes instructors, professionals, team members, and artifacts.*

Keywords: Activity theory, discourse analysis, speech acts, design thinking, design identity, design education, engineering education, industrial design

1. Background: Design Learning in Engineering Education

Design learning occurs across a range of fields including architecture, the arts, computer science, and engineering. However, each of these fields constructs its design curricula differently. Programs in architecture and the arts, for example, typically employ studio models in which students begin designing immediately within the context of robust, ongoing peer and expert review. In contrast, programs in engineering, though they may include early "cornerstone" design experiences, more often employ a model in which students spend the first three years of their undergraduate program accumulating technical expertise through coursework that does not offer as many design opportunities. This expertise is then applied during their senior year when these students engage in a team-based capstone design project. In contrast to architecture and arts models, however, even these design-based courses engineering design environments rarely employ a studio model; teams typically work in individual labs rather than large open spaces (Pembridge & Paretti, 2010).

As engineering educators, our interest lies specifically in enhancing design education within engineering by exploring and learning from the pedagogical practices of other design fields. Because the implications of this study focus on the engineering classroom, we provide a brief overview of engineering design education research to frame the study.

Work in engineering design education includes curricular and pedagogical research, often focused on capstone courses. Capstone, or senior, design courses began to emerge in the mid 1990s in response to the theoretical orientation of engineering education that followed World War II (Dutson, Todd, Magleby, & Sorensen, 1997). Studies by Todd et al. (1995), Howe (2010), and Paretti and Pembridge (2010) have tracked practices in capstone courses at roughly five-year intervals. Prominent engineering design educators, such as Dym (1998), Little and King (2001), and Sheppard and colleagues (1997; 2008; 2001), have described approaches to increasing the practical component of the curriculum via such capstone courses, and increasingly called for additional design experiences such as cornerstone (first-year) courses and design across the curriculum.

These general curricular frameworks have been complemented by detailed work on both teaching and assessing engineering design skills. Research has included: design learning outcomes (D. Davis et al., 2006) and assessment (D. Davis, Beyerlein, Harrison, Thompson, & Trevisan, 2007); design behaviors of first-year, senior, and expert engineers to more fully understand learning trajectories (Atman, Adams, et al., 2007; Atman, Rhone, et al., 2007); and strategies for specific elements of the design process such as idea generation (Linsey & Becker, 2010); gender and product orientation (Okudan & Mohammed, 2006); and reflection (Adams, Turns, & Atman, 2003).

Equally relevant to this study, a number of researchers have begun exploring the practices of engineering design educators to understand effective coaching and mentoring practices (Manuel, McKenna, & Olson, 2008; Pembridge, 2011; Pembridge & Paretti, 2011; Stanfill, Mohsin, Crisalle, Tufekci, & Crane, 2010; Taylor, Magleby, Todd, & Parkinson, 2001). Design "teaching" has most often been described as a practice of coaching or mentoring, relying heavily on the processes of questioning and advising student teams as they both learn and practice engineering design. Little work in this area to date, however, has looked closely at the designer/design mentor dialogue in engineering to better understand how this dialogue shapes design learning, or considered the role of prototypes (a common product of design courses) in these interactions. More broadly, few if any studies have compared the practices of engineering design educators to those of design educators in other fields. Studies by Matthews and Heinemann (2012) and Carlile (2002) consider the role of language within design scenarios situated within the industrial setting including software development and product development. Ewenstein and Whyte (2009) investigate the use of artifacts as mediating tools of communication between students and experts in an architectural design course. Martin and his team (2011) have explored pedagogies for interdisciplinary product design in courses with engineering, industrial design, and marketing students and faculty. And Luck (2012), Dong (2007), and Oak (2011) introduce the use of methods such as ethnomethodology, conversation analysis, and symbolic interactionism as viable means to study how design is performed throughout a variety of contexts. These studies reside across multiple contexts and disciplines, and they inform and strengthen our guiding theoretical frameworks as we build on research that considers the crucial and performative roles of both language and artifact usage in design communication.

2. Theoretical Frameworks

To guide our study of design learning and the interactions among students and experts, we use activity theory as a lens to describe design review sessions. We then employ discourse analysis to analyze the mediating roles of language and design artifacts within these sessions.

Activity theory (Engeström, 1987; Engeström & Middleton, 1998) guides our understanding of design review sessions as systems in which subjects (student designers and design instructors and external reviewers who act as experts) operate within a set of rules, communities, and work structures, mediated by language and by student-developed artifacts, to both practice design and facilitate design learning. Activity theory thus provides a meaningful way to identify salient components of the design review sessions used in this analysis, and simultaneously provides a systematic framework for comparing review sessions across contexts and phases.

Within these systems, we then focus on two mediating tools, language and design artifacts, using discourse analysis (Gee, 2005), supplemented by Austin's speech act theory (1975). Taking Gee's definition of discourse as "language in use" (2005, p. 7) through which individuals enact activities and identities in particular contexts, we explore subject performance through language. In these approaches, language is not a transparent medium of transmission but a dynamic tool for constructing relationships and making meaning. Discourse analysis thus offers a lens to analyze linguistic moves as instructors, evaluators, and student designers interact with one another, as well as what those moves accomplish. In drawing on Gee's work within the context of activity theory, however, we include not only the language individuals use, but also the physical artifacts that function as symbolic tools, in concert with words, to describe, explore, evaluate, and revise designs. Thus although we treat language and design artifacts as independent mediating tools for the purposes of analysis, we have selected these two mediating tools precisely because they are intricately connected with the design review space. That is, the talk within these review sessions focuses on what the novice designers either will design or have designed, as represented through artifacts such as drawings and physical prototypes. Through these artifacts the students seek to embody their design ideas, and the artifacts (or sometimes their absence) are often at the center of the discussion. They provoke and shape the ongoing dialogue between the experts and novices, and the surrounding discourse in turn makes meaning of these artifacts in the learning process. Additionally, the very act of engaging in this type of discourse instantiates the practice and enactment of developing professional identities.

3. Methods

To explore the mediating functions of language and artifacts in design learning, we use a multi-case approach in which we analyze a range of design review sessions across two majors. Specifically, we analyze design reviews from courses in Mechanical Engineering (ME) and Industrial Design (ID). The two fields share a focus on product design, but employ markedly different processes, practices, values, and pedagogies. As such, they offer a productive pairing to explore the ways in which language and artifacts interact in design and design learning. ME is, in many respects, the prototypical design field within engineering; ME has a strong history of design research, beginning with Herbert Simon's work (Simon, 1996), and discussions of engineering design processes often rely on models developed by and for mechanical engineers in which designers iterate through problem definition, idea generation, and testing and evaluation (e.g., Atman, Deibel, & Borgford-Parnell, 2009; D. C. Davis et al., 2003; Dym, Agogino, Eris, Frey, & Leifer, 2005; Safoutin et al., 2000). Moreover, mechanical engineering curricula typically follow the traditional engineering approach, with the first three years of undergraduate education devoted to topics such as thermodynamics, statics, differential equations, and fluid mechanics, followed by a year-long capstone design project grounded in the ME design process. Like ME, ID focuses on product design, but typically employs a studio approach that begins in the first year and continues across the curriculum. The process focuses early and iteratively on ideation, including activities such as sketching, pin-ups and on-spot evaluations of concepts, and establishing personas for product ideas in order to define problems and create conceptual solutions (Coupey, et al. 2010; Martin, et al., 2011).

3.1 Data Collection and Participants

The data were drawn from the Design Review Conversations database (Adams & Siddiqui, 2013). For this study, we selected the data sets for the year-long, team-based senior-level capstone design course in ME, in which the faculty advisor serves as the expert; and the semester-long, client-based, individual-based junior-level design course in ID in which both the instructor and the client act as experts in different review sessions. Details on the data collection are described in Adams and Siddiqui (2013). Tables 1 and 2 summarize the data available for each course.

In each case, we used both the review transcript and the corresponding video recording to analyze language use as well as the physical use of the design artifacts. To facilitate detailed artifact analysis, descriptions of physical actions were added to the transcripts for the ME Final Design Review and the ID Client Review during critical events in which the design artifact (prototype or model) played a major role in the dialogue between students and experts. Course descriptions, student reports, and related data served as supplements to inform our understanding of each review as a distinct activity system.

Table 1: Mechanical Engineering Design Reviews

Team Name	Outcome	Conceptual Design Review (CDR)	Final Design Review (FDR)	Competition
Prop Team	High: Selected for Competition	X	X	X
Cap Team	Low: Failed at the FDR	X	X	
Robot Fish Team	Medium: Completed FDR but not selected for competition	X	X	

Table 2: Industrial Design Reviews

Student Name	Outcome	First Review	Second Review	Client Review	Looks-Like Review	Final Review
Addison	High: Competition winner			X	X	X
Adam	High: Competition winner		X	X		X
Alice	Very High: Competition winner; awarded internship		X	X		X
Esther	No award			X	X	X
Lynn	No award	X		X		
Sheryl	Medium-High: Competition 2nd-tier winner		X	X	X	X
Todd	No award	X		X	X	X

3.2 Analysis

Data analysis was conducted in three phases. Phase 1 included the analysis of video data using activity theory to provide a systematic description of each review. Phase 2 included the review and coding of video and transcript data using discourse analysis and speech acts to identify linguistic patterns in discussions. In Phase 3, a subset of the video and transcript data was reviewed using discourse analysis, but focused on the design artifacts to identify their mediating functions within the review systems. These three analyses were integrated to inform the ways in which students and experts engaged in meaning-making and constructed design identities.

3.2.1 Phase 1: Activity Theory

In Phase 1, each design review was analyzed using activity theory (following Engeström (1987)) as a lens to identify the subject, instruments, rules, community, object, division of labor, and outcome. This analysis enabled us to systematically describe the relationships between student designers, instructors, and expert evaluators within an evaluative environment governed by socially-constructed rules and linguistic practices. Additionally, it served to identify the dominant artifacts mediating each review. Figure 1 presents a sample of this analysis for the Prop Team (ME) during their Conceptual Design Review (CDR). As noted earlier, this approach provided a systematic review of each type of review to facilitate subsequent analyses.

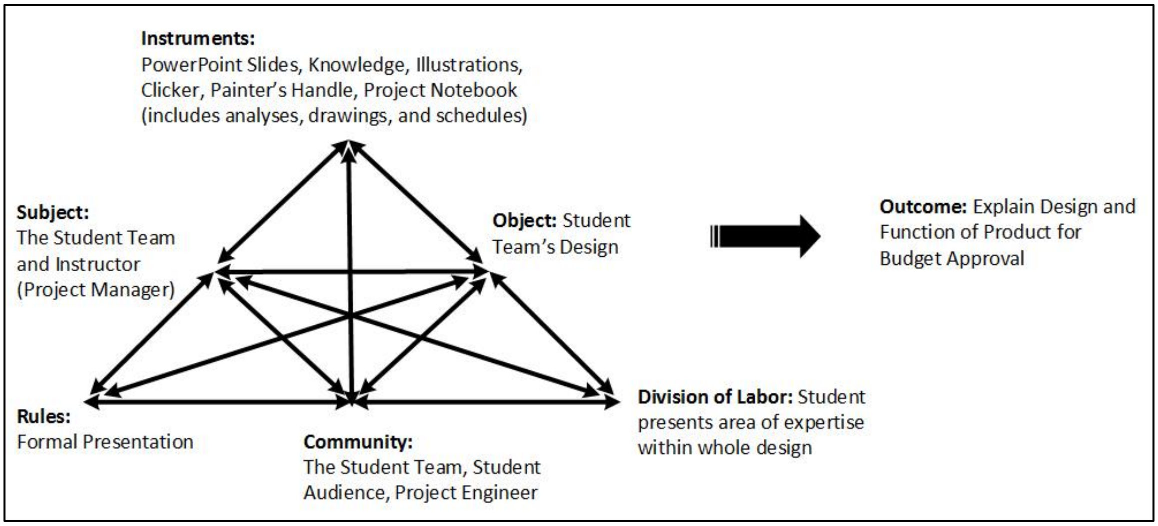

Figure 1: Example of Activity Theory Analysis

3.2.2 Phase 2: Discourse Analysis

Using open coding (Creswell, 1998) and guided by the principles of discourse analysis (Gee, 2005), we immersed ourselves in the data and allowed patterns to emerge as we focused on the ways in which activity system subjects (students and experts) communicated verbally with one another. Observations were continuously recorded in a research notebook and were refined through repeated review of the video data to determine implied meanings exhibited through tone, context, and topic.

Given the range of speech patterns present in the review sessions and our interest in design pedagogy, we focused on the discourse of the experts to explore how these mentors use language to prompt, guide, and validate students' designs and design processes. Table 3 summarizes the expert speech acts identified across the review sessions. Note that in the codes Understand and Clarify, we use a single code for simplicity, but since statements and questions have different inflections in these codes, we distinguished between questions and statements in the discourse analysis.

These speech acts provided a general indication of patterns in the mentor/student dialogue, but also highlighted similarities among review types for the ME and ID students and thus shaped the second level of discourse analysis. As described in more detail in Section 4.2, mentors in the ID Client Reviews (CR) and the ME Final Design Reviews (FDR) exhibited similar discourse patterns, in which questions rather than statements served as the dominant mode of interaction.

Table 3: Expert Speech Acts

Discourse Action Code	Description
Acknowledge Enthusiasm	Statements that acknowledge or encourage the students' enthusiasm for the design or some specific design element or specifically ask students about their preferences regarding the design.
Advise	Statements or questions in which the experts describe what they would do or offer direction to guide the students' next steps. Unlike Commands (below), advice is proffered as a suggestion rather than a directive.
Challenge	Statements or questions that challenge the designers and their explanations or thinking.
Clarify	Statements that clarify a previous comment or questions that ask students to clarify a previous statement question.
Command	Statements that direct the students to act, most often directing them to revisit or further research aspects of the design based on lack of student knowledge.
Demonstrate Expertise	Statements or questions in which the expert draws on his or her own knowledge, often to push students beyond their current knowledge or thinking.
Evaluate	Statements or questions that explicitly evaluate the student's design.
Express Satisfaction	Statements that express satisfaction with the student's response.
Extend	Statements or questions that extend the design beyond its current application or scope, indicating their interest in the design or its potential.
Promote Reflection	Statements or questions that prompt students to reflect on the process and/or their learning.
Protect	Statements that protect the students from criticism by others, most often when the course instructor intervenes between the students and outside experts.
Understand	Statements that indicate understanding or questions that seek to better understand the design concept.

3.2.3 Phase 3: Artifact Analysis

In the final phase of analysis, we focused on the roles that artifacts played during design reviews. To provide meaningful comparisons between the ME and ID sessions, we focused only on the two review sessions that were most comparable based on the results of Phases 1 and 2: the ME FDR and the ID CR. Although there are differences, both reviews relied heavily on the use of prototypes and both were dominated by dialogic question/answer sequences between experts and students – often around the artifacts themselves. Moreover, as the artifact analysis progressed, it became clear that the artifacts themselves were critical components of two of the speech acts that dominated these reviews – Understand and Evaluate.

Using the video data and transcriptions of actions, observations of artifact usage and type were recorded, focusing on the role of the artifacts in the discussions. Additionally, subjects interacting and engaging with artifacts were also observed (e.g. students letting the instructor hold, touch, and operate their developed prototype). As noted, the artifacts were particularly integral to speech acts coded as Understand and Evaluate, and thus artifact analysis provided ways to nuance both of these speech acts and explore the intersections of talk and object. Table 4 displays the codes that guided this analysis.

Table 4. Artifact Codebook

Code	Description
1. Understanding	
1.1 Illustrate/Explain	Instructors, clients, or students use the artifact to understand or to communicate basic, visual characteristics of a design concept.
1.2 Explore/Discover	Instructors, clients, or students use the artifact to understand or to communicate the function or demonstrate the use of a design concept.
2. Evaluation	
2.1 Noting Positives	Instructors, clients or students identify positive aspects or components of the design.
2.2 Noting Negatives	Instructors, clients or students identify negative aspects or components of the design.
2.3 Suggesting Modifications	Instructors, clients or students provide suggestions and/or areas for improvement.

4. Results

4.1 Design Review Activity Systems

As indicated in Tables 1 and 2, the dataset included multiple types of design reviews across two different disciplines, including both formal presentations in which students stood at the front of a classroom and presented their concepts to classmates and/or experts and informal presentations in which the students discussed design concepts in a more informal setting with just the course instructor.

Because the primary results presented here focus on dialogic sequences and artifact use in the ME Final Design Review and the ID Client Review, we provide only brief descriptions of the other reviews and describe the FDR and CR in more detail. These descriptions are framed by our analysis of each activity system, but for brevity we provide a synthesis rather than the detailed system analysis of each review.

4.1.1 Industrial Design Client Reviews

Although covering only one semester, the Industrial Design data subset included five different types of design reviews – two more than the year-long ME course: 1) the First Review, 2) the Second Review, 3) the Client Review, 4) the Looks-Like Review, and last, 5) the Final Review.

The First, Second, and Looks-Like Reviews were informal, one-on-one meetings between each student and the instructor. These reviews were conducted in a classroom at a table where the student and instructor sat together and discussed preliminary sketches (First Review) and more developed, to-scale sketches (Second Review) of design ideas, or student-created artifacts (computer drawings and prototypes) of the selected design (Looks-Like Review). Working side by side at a table, the expert and student created a shared work environment as the student laid out artifacts in front of the expert so that they could both see, discuss, and interact with those artifacts. Importantly, the First and

Second Reviews occurred prior to the Client Review, while the Looks-Like Review occurred after the Client Review so that the instructor could help the student process the client feedback and prepare for the Final Review.

The Client Review was held in the same room as the First, Second, and Looks-Like Reviews; however, the Client Reviews were formal presentations in which the students used storyboards and prototypes to present their design concepts to client evaluators, the instructor, and peers. The goal of the review was for the students to receive client feedback on their top design concepts so that they could select and refine a design for their final presentation to the client.

Dressed in professional business attire, students presented their designs at a projection screen at the front of the room, immediately in front of a table holding a computer and other equipment. To the right of the computer, small easels and other objects were used to prop up students' storyboards. The table was also used to display students' models in front of the evaluators. At the table facing the student sat a panel of external evaluators and the course instructor. Behind the evaluators and instructor were rows of computer desks at which other students sat.

Students formally presented three concepts for evaluator feedback, followed by a question-and-answer discussion. Interestingly, as in the informal reviews, the evaluators sat in very close proximity to the student designer, albeit on opposite sides of the table, and were able to interact with the models as students presented.

The Final Reviews were formal presentations held on site at National, the company sponsoring the project. Standing in a conference room arranged classroom-style, the students used PowerPoint, a physical prototype, and a design poster to present their design concept to the clients. The presentation was followed by a question/answer session, and the clients used these Final Reviews as the basis for selecting the winning design. In this particular case, the clients selected three top winners, with one receiving an internship (Adam) and one secondary "future winner."

4.1.2 Mechanical Engineering

The Mechanical Engineering data subset included three different design reviews: 1) the Conceptual Design Review, 2) the Final Design Review, and 3) the Competition Presentation.

The Conceptual Design Reviews (CDR) were formal reviews conducted in a traditional classroom; student teams, dressed in business attire, presented their preliminary design work to the instructor and their classmates via PowerPoint presentations. The instructor asked questions throughout the presentation, and concluded with go/no go decision for continuing.

The Final Design Reviews (FDR) were the second of the three reviews, in which students showed their finalized physical prototypes to the instructor in order to obtain the instructor's approval of their design and prototype to proceed to the department design competition. The instructor, with minimal assistance from the course's teaching assistant (or project supervisor), served as the expert in these sessions. The FDRs occurred in the laboratories where the students worked. In some instances, other students were present in the lab, although they did not participate in the FDR. In other instances, only the design team, the instructor, and another project supervisor were present. The instructor would sit at a worktable in the lab, facing the students. The students either stood at the table with him (Robot Fish Team) or at a work counter and cabinets in front of the table (Prop Team and Cap Team).

These presentations were informal (students were dressed in casual clothing) and followed a general question-and-answer format. The instructor began by asking each team three primary questions: 1) Is the prototype fully assembled? 2) If not, what are some changes that you have made since the Conceptual Design Review (CDR)? and 3) Is the prototype fully functional per the changes since the CDR? Students were then given approximately five minutes to gather their thoughts and provide answers for each question. The instructor emphasized that brief, succinct answers were preferred. The instructor then allowed the students to present their responses and followed up with any additional questions or clarifications. Unlike the first review (the CDR), the instructor generally did not interrupt students during the presentation.

Because these presentations were informal, each team took a different approach. One team did not have a fully assembled, fully functional prototype to present and therefore did not complete the FDR; another team broke questions down into topics and each team member presented on different design components; the third team presented a video to the instructor and then engaged in an informal discussion with him. Immediately following the presentation, the instructor would tell the students their final grade for the course.

The Competition Presentations were formal presentations in front of a jury of external experts. Dressed in business attire, the student teams used both PowerPoint and their prototype to present their design to this jury, and the presentation was followed by Q&A. Only the Prop Team was selected to advance as far as the competition presentation.

4.1.3 The ID CR versus the ME FDR: A Comparison of Activity Systems

As noted in Section 3, most of the analysis in the following sections focuses on the FDR and the CR because, based on the both the discourse analysis and the artifact analysis, these two reviews share two critical features with respect to the mediating tools:

1. Both are dominated by question/answer sequences between the expert(s) and the student(s).
2. Both rely on physical prototypes (rather than PowerPoint presentations) to explain the design under review.
3. In addition, both reviews are preparatory to a final "competition" review before a panel of judges, and thus have related goals and a similar division of labor between the experts and the students.

At the same time, from an activity system perspective, the two types of reviews also have notable differences:

- The ME projects are all team-based, in which team members may have different areas of expertise relative to the design; as a result, students talk to and with each other as well as the experts. The ID projects, in contrast, are all individual, with a single designer responsible for the entire concept.
- The ME FDRs are informal sessions between the expert and the student team, while the ID CRs are formal sessions in which other students in the course are also present as the audience. As a result, the rules as well as the community context differ between the two systems.
- Although both reviews are preparatory to a competition presentation, the ME FDRs appear more evaluative, with the expert deciding whether the team can progress to the next level. The CRs, in contrast, are more dialogic, in which the goal is to provide useful feedback to prepare for the next level, though they also include a strong evaluative component. The two systems thus have overlapping, but not identical, outcomes.
- Not included within the activity system perspective, another difference worth noting is the structural difference of the overall review process threaded throughout the ME and ID design courses. Prior to the CR, the ID students had completed two informal reviews with their instructor; the CR was the first instance in which the students were being formally evaluated with the instructor and external clients present. The ME students, in contrast, had only one formal evaluation with their instructor in front of their classmates prior to the FDR, though they may have also had informal meetings throughout the course to discuss the project as it developed.

Both these similarities and differences are critical to exploring the ways in which the tools operate, but, as the following sections suggest, the presence of a robust prototype plays a critical role in mediating each design discourse.

4.2 Discourse Analysis

As described in Section 3.2.2, the experts' discourse was analyzed to identify 12 distinct speech acts. However, although each of these acts was present across the data, certain speech acts dominated the different reviews. To provide a basis for comparison, the results are reported in terms of the percent of total coded expert speech acts per transcript. In quantifying the qualitative data here, our aim is to identify general patterns that merit further exploration and that inform the artifact use described in Section 4.3.

4.2.1 Industrial Design

For the full analysis of all ID students across all reviews, please see Appendix A. For simplicity here we discuss the most salient results.

The First and Second Reviews, in which students met individually with the course instructor, were dominated by Advise (43%-65%), followed by Evaluate (16%-26%). Both sessions also showed a higher comment density, with 3.2-5.8 coded comments per minute, as might be expected in one-on-one sessions around design ideas. These reviews were also dominated by statements rather than questions, which account for less than a fifth of the expert comments (3-14%).

The Client Reviews had a much lower comment density (1.3 – 2.2 per minute), which is consistent with the focus on students' formal presentation of their design ideas. Also consistent with the goals of the activity system, questions dominated the experts' talk, accounting for anywhere from 33-75% of the expert comments. Unlike all the other ID reviews, the expert speech acts in these Client Reviews also showed much more variation across participants, as shown in Table 5.

Table 5: Expert Speech Acts in ID Client Reviews

	Addison*	Adam*	Alice*	Esther	Lynn	Sheryl	Todd
Advise	11.1%	0.0%	0.0%	18.2%	0.0%	0.0%	12.5%
Challenge	11.1%	13.3%	0.0%	0.0%	0.0%	12.5%	25.0%
Clarify	11.1%	13.3%	0.0%	27.3%	42.9%	12.5%	25.0%
Demonstrate Expertise	22.2%	13.3%	11.1%	9.1%	0.0%	0.0%	0.0%
Evaluate	22.2%	26.7%	44.4%	9.1%	0.0%	0.0%	12.5%
Extend	11.1%	0.0%	11.1%	9.1%	0.0%	0.0%	12.5%
Understand	11.1%	33.3%	33.3%	27.3%	57.1%	75.0%	0.0%
% Questions	33.3%	40.0%	33.3%	45.5%	57.1%	75.0%	37.5%
Density (coded comments/min)	1.5	2.1	1.5	2.2	1.4	1.3	1.3

*Denotes competition winner

Several speech acts were notably absent, including both commands and expressions of satisfaction. Clarifications were prominent in both Esther's and Lynn's sessions, as were comments and questions related to understanding, but these same acts occurred much less frequently in other students' sessions. Note, too, that the three competition winners' sessions had the highest percentage of evaluative comments, with Alice, selected for the internship, at 44%.

The Looks-Like Reviews, also individual student/instructor meetings, were even more heavily dominated by Advise (36% for Esther, but 58%, 59%, and 68% for Addison, Todd, and Sheryl, respectively). However, Evaluate dropped considerably (0-6%). Again, these patterns are consistent with the goal of the activity, in which students were working with their instructors to process the client feedback as they developed their final design. The density of the comments also rose again, from 3.5-5.5 coded expert comments/minute. Questions accounted for slightly more of the expert comments (14-31%), but still remained relatively low.

Finally, the Final Reviews, in which the students formally presented their design concept to the client, showed much less variation across students and were dominated by three speech acts: Clarify (17%-37%), Evaluate (10-38%), and Understand (22-60%). Comment density here paralleled the Client Review, for similar reasons (1.1-2.0 coded comments/minute). Questions accounted for 25-40% of the expert comments for most students; notably though, Alice was questioned most heavily, with 60% of the expert comments in her sessions framed as questions.

Upon analyzing data collected for all review sessions, the interactions between the instructor and student during individual, one-on-one meetings (the First and Second Review and the Looks-Like Review) were the richest and most collaborative. These interactions centered on design artifacts (sketches and then models) and were heavily marked by advice from the expert to the student (on the order of 50% on average). These sessions also had notable components of evaluation (13%) and understanding (13%) as the subjects worked together within the activity system to develop and refine design ideas. The client sessions, in contrast, as suggested by the activity system itself, tended to be more focused on understanding and clarification as the designs were reviewed (rather than developed).

4.2.2 Mechanical Engineering

The ME teams' review sessions in general show patterns much closer to the ID Client and Final Reviews rather than the one-on-one sessions between the ID instructor and each student. That is, although the subjects in the ME CDR and ME FDR are similar to the ID instructor/student sessions in that they include only the instructor and the students, the corresponding discourse patterns more closely match the ID sessions with clients (see Appendix A for comparison). With fewer teams and review sessions, we present the full data set here in Table 6.

As Table 6 indicates, there is some variation in the discourse patterns across both teams and reviews, though in general the sessions included substantial questioning, and the Final Design Reviews had a strong evaluative component. Acknowledge Enthusiasm did not show up in any of the ME review sessions, again linking them more closely to the ID Client Reviews. Both the CDRs and FDRs included substantial Clarification and Understanding, but surprisingly, showed little evidence of Advise, except in the CDR for Robot Fish Team, in which the instructor was helping the group to figure out next steps, and the FDR for the Cap Team, who did not have a functioning prototype and were effectively failing. The Cap Team was the only one in which the expert's speech included Command (CDR). Notable here as well is that the highest variety in speech acts occurred in the FDR for the Prop Team – the team that was selected to participate in the final competition.

Across the review sessions, as these speech acts were performed, varying levels of implied evaluation are taking place that both define "good design" and guide learning (Wilson, 1996). Positive speech acts such as extending the students' work to new contexts, exhibiting understanding, and expressing satisfaction provide students with cues that they are conducting "good design" practices. Negative speech acts such as commands or interruptions allow the instructors and evaluators to make linguistic moves that implicitly demonstrate to students their adoption of poor design practices. We note, however, that literal speech alone does not inherently imply the level of quality evaluated within these design scenarios. Instructor tone, discourse, and timing are all contextual factors that impact how the discourse was interpreted by students as being positive or negative evaluations. For example, tone and context further informed what was happening beyond the transcripts to determine the actions that were happening (i.e. sarcasm).

Table 6: Evaluator Speech Acts for ME Review Sessions

	Conceptual Design Review			Final Design Review			Comp
	Prop Team	Cap Team	Robot Fish Team	Prop Team	Cap Team*	Robot Fish Team	Prop Team
Advise	0.0%	0.0%	24.2%	7.1%	30.8%	5.6%	0.0%
Challenge	7.7%	20.7%	12.1%	7.1%	7.7%	0.0%	17.1%
Clarify	15.4%	17.2%	16.5%	17.9%	15.4%	7.4%	12.2%
Command	0.0%	6.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Demonstrate Expertise	2.6%	6.9%	15.4%	3.6%	0.0%	0.0%	9.8%
Evaluate	12.8%	3.4%	5.5%	25.0%	30.8%	40.7%	0.0%
Express Satisfaction	7.7%	13.8%	5.5%	3.6%	0.0%	7.4%	2.4%
Extend	0.0%	0.0%	0.0%	3.6%	0.0%	0.0%	9.8%
Promote Reflections	0.0%	0.0%	0.0%	3.6%	0.0%	13.0%	0.0%
Protect	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.9%
Understand	53.8%	31.0%	20.9%	28.6%	15.4%	25.9%	43.9%
% Questions	48.7%	44.8%	25.3%	67.9%	23.1%	46.3%	48.8%
Density (coded comments/min)	1.9	1.3	2.2	2.3	1.9	2.5	1.7

*Not allowed to next step

4.3 Artifact Analysis

In order to analyze the impact of artifacts on discourse in design settings, we coded the subset of design reviews that served as formal precursors to the final review, in which students presented their designs to instructors and industry professionals via artifacts such as prototype models, storyboards, videos and slide presentations. In general, we found that the more that participants interacted with the artifacts, the richer the discourse about the student designs.

As described above, given the similarities in both artifact use and discourse patterns in the ID Client Reviews and the ME Final Design Reviews, we use those two review sessions as the basis for our artifact analysis. Of the 7 Client Reviews, we selected two for analysis here that reflect markedly different discourse patterns and student outcomes. As shown in Table 5, the expert discourse in Adam’s Client Review was distributed among a range of speech acts (Challenge, Clarify, Demonstrate Expertise, Evaluate, and Understand), and 40% of the experts' discourse used questions. Adam's session was also among the two most dense, with 2.1 coded expert comments per minute. The expert discourse in Lynn's Client Review, in contrast, included only two of our speech act codes, clarify and understand, and was dominated by questions (57%) as the experts sought to understand her design.

Like the Client Reviews, the ME Final Design Reviews relied heavily on questioning, and the three teams offer distinctly different discourse patterns, as seen in Table 6. With the Prop Team, the discourse was distributed across a full range of speech acts (Challenge, Clarify, Demonstrate Expertise, Evaluate, Express Satisfaction, Extend, Promote Reflection, Understand), whereas the failed Cap Team was dominated by Advise and Evaluate. For the Robot Fish Team, which was allowed to move forward but not selected for competition, the expert discourse was dominated by evaluation and understanding.

Table 7. Numerical Summary of Codes in Presentations

	Illustrate/Explain	Explore/Discover	Noting Positives	Noting Negatives	Suggesting Modifications
ID: Adam	2	3	4	2	3
ID: Lynn	4	2	1	0	0
ME: PT	4	4	1	0	0
ME: RFT	13	4	10	2	0
ME: CT	1	1	2	4	0

Table 8. Numerical Summary of Time and Turn-Taking during Critical Events

	Presentation Time	Critical Event Time	Speaker Turn-Taking	Artifact Turn-Taking	Artifacts Used
ID: Adam	7:21	03:55-07:00 (03:05)	25	10	Slide Pres.: 1 Storyboards: 3 Video: 0 Models: 3
ID: Lynn	5:24	00:08-00:10 (00:02) 03:37-05:12 (02:45)	14	0	Slide Pres.: 1 Storyboard: 1 Video: 0 Models: 3
ME: PT	11:12	06:11-07:09 (00:58) 07:13-09:22 (02:09) 10:37-10:57 (00:20)	29	6	Slide Pres.: 1 Storyboard: 0 Video: 1 Models: 1
ME: RFT	22:17	00:12-07:11 (06:59) 07:26-08:27 (01:01) 15:47-16:20 (00:33)	80	11	Slide Pres.: 0 Storyboard: 0 Video: 1 Models: 1
ME: CT	03:54	03:54	40	0	Slide Pres.: 0 Storyboard: 0 Video: 0 Models: 1

Table 4 (displayed previously in Section 3) lists the codes and their descriptions; Table 7 displays a numerical summary of the coding results; and Table 8 displays a numerical summary of time and artifact turn-taking during critical events. The term "critical event" indicates portions of the presentations during which student design artifacts played a role in the discussion. Artifact turn-taking is counted when the possession of a model transferred immediately from one person to another (e.g., when Max sets the model for Concept 1 in front of himself and Darren reaches across the table to touch the model to hold it while he speaks).

The following three sections compare the two Industrial Design presentations and the three Mechanical Engineering presentations, and, finally discuss patterns found across all five presentations.

4.3.1 Industrial Design "Client Review" Presentations

Adam: Robust Artifact, Robust Discourse. Overall, Adam's presentation was successful both in terms of earning praise during the critique and generating productive feedback on his designs. As Adam presents his three concepts, he briefly describes each based on his PowerPoint slides. As he is speaking, the clients pick up and hold the models for his designs. They study them and ask Adam various questions about each design. Near the mid-point of the presentation, the clients pass one model among each other as they evaluate the design. This interaction is also reinforced as Adam asks the clients for more feedback and brainstorms a few ideas with them. The presentation concludes with a positive evaluation from the clients. This presentation is brief (approximately 7 minutes), and almost half of the presentation is spent in discourse interactions between Adam and the clients as they interacted with the artifacts and developed conceptual design ideas with one another. Specific analysis of the discourse is presented in the following paragraphs.

The models are at the center of the clients' attempts to understand Adam's designs. At a simple level, they facilitate *Understanding—Illustrate/Explain* (code 1.1). For example, after Adam finishes speaking from the slides, Darren asks a question about Concept 3, "*So, I take it, in the bottom of that there is a void that takes the shape of the seat?"* Adam answers by replying *"Yeah"* and uses the corresponding model to show the client how the seats may be nested within one another for storage. Rotating a piece of a model in his hand so that it is in the same position as the piece remaining on the table, Darren again asks Adam a question, this time about Concept 2: "*This guy here, this is exactly the same part, right? It's two of the same part?"* Adam simply replies *"yeah"* again as the client flips the piece back over and rests it on top of the first piece in its original position.

At the *Explore/Discover* level of *Understanding* (code 1.2), the artifacts facilitate discussion about the functional aspects of the design, and promote interaction between the multiple clients. For example, Devon picks up the model for Concept 3—the design that could be nested, as Adam had explained to Darren—and starts to explore potential functions:

[Devon turns the model over in his hands, inspecting it.]
Devon: *[Speaking to Client 1]* You see…it…first these are two different heights to balance this one and the last one. *[Looking over to Jason*

and Max] Is this thing your 16-inch sit and this one is a little bit higher? *[Sets down the model on the table and points to the portions of the model he is talking about.]* It's taller, almost bar height.

Darren: Taller…

Devon: So for me then to –

Darren: And then sit.

Devon: And then sit as well. You could turn it around and use it as a drawing table.

Adam also joins in this interaction, using the model as a focus for exploring possible adjustments that he could make to the design and how the functions of the design may change:

[Jason speaks and then there is a brief pause in the conversation.]

Adam: What would you think *[picks up the model from the table*] if I made this space bigger *[points out the negative space on the model with his fingers, showing the clients]* and the cushion a bit smaller *[pointing out the cushion on the model]* so then you could…if you did want to pursue that you could take the cushion and store it in here *[points back to the negative space in the model].*

Jason: Down below? *[Nods*] Yeah. I mean, I think… *[Adam sets the model for Concept 3 back down on the table*] …yeah, that's definitely something to experiment with.

The clients also appear to be basing positive and negative feedback (codes 2.1, 2.2) on their interactions with the models, and these comments lead to suggestions for modifications (code 2.3):

[Darren slides the model for Concept 3 toward himself, picks it up]

Darren: I think this idea is kinda neat…

[Jason reaches across the table and picks up the model for Concept 3 from Darren. He rotates it in his hand as he speaks.]

Jason: The other thing, I think…the versatility I think is what's strongly towards a couple of your ideas and I see this being a very versatile, functional piece and in fact you can use it as a table. *[Jason flips the model over so that the seat turns into a table]* What I would like to see is almost take the cushion…be removable from this as well *[points to a specific piece of the model],* kind of what you did with the third concept so now you can remove the cushion, flip it over *[flips the model over as he speaks],* sit on the cushion, use this potentially as a writing surface *[taps the bottom of the bench, now facing up*], and then you could also – *[flips the model vertically]*

Darren: Yeah, you could flip it up like that.

Jason: - flip it vertically to now it's a stand-at-height table possibly.

Comments about possible problems (code 2.2) also lead to suggestions (code 2.3). For example, Max rests his hand on the model for Concept 3 after Adam sets it back down on the table and taps the model with his fingers as he speaks:

Max: What materials are you looking at for the outer portions?
Adam: Uh, wood laminate.
Max: Wood laminate? Okay. The only thing that could turn up there is scratching. If you were gonna sit it like this *[flips the model over on its side]* and then you decided you want to flip it up *[flips the model vertically on one end],* how do we keep that surface area clean? I mean there's ways to get around that.
[Max then removes his hands from the model.]
[Darren reaches over to take the model of Concept 1 from Max and slides it to a more central location on the table. He then uses his fingers to demonstrate where on the model is modification could take place.]
Darren: You could have a range area of a - or a bar or something that doesn't allow this to actually sit on the surface. *[Looking at Max as he speaks.]* But I mean there's all kinds of…that's pretty versatile.
[Darren removes his hand from the Concept 1 model and leans back in his chair.]

In the last three minutes of video (the time frame in which most of this discourse and artifact interaction occur), the models are passed around frequently—a total of seven times between the clients and the student. All participants (with the exception of the instructor) were huddled around the table discussing various aspects of the designs and gave Adam a lot of feedback in a short amount of time. At one point in time, each model is being held by a different client.

Lynn: Weak Models, Limited Discourse. In contrast to Adam's presentation, Lynn's models appear to be fragile and the model designs do not match the designs she is presenting in her slide presentation. Also, she places one of the models behind the storyboard easel, effectively "hiding" it from the clients and keeping it out of their reach. Consequently, the clients do not physically interact with her models; they indicate confusion about how the product should look and function, and must rely on the slides and her verbal explanation. Although the clients end the critique with a polite positive comment, the feedback is impoverished in comparison to the session with Adam. Specific analysis of the discourse is presented in the following paragraphs.

In terms of *Understanding—Illustration/Explanation* (code 1.1), the artifacts that Lynn uses do not facilitate discussion. Although the models and the storyboards are placed on the shared table space between Lynn and the clients (except for the "hidden" model for Concept 3), the discussion revolves primarily around the slide presentation, which the clients attempt to use to understand the design concepts. For example, in trying to understand the basic form of Concept 3, Jason looks between the slides (which show the concept in one piece) and the storyboard (which shows the concept in two pieces). As noted, Lynn has placed the model for Concept 3 out of sight and out of reach.

[Lynn finishes speaking about her concepts and stands in front of her PowerPoint slides. The clients remain sitting at the table.]

Jason: So the third one again, you're saying that there's actually a separation between the layers of plastic for storage?

Lynn: Yeah, right so - because they are soft they can clamp base.

Jason: Okay.

[Jason looks back up at the PowerPoint slides. A long pause in discussion, approximately 10 seconds, ensues.]

Without a model to physically demonstrate the form of the design (and owing as well to the conflict between the storyboard and slide images), the communication of the design is unclear. A similar lack of clarity occurs when a model is present, but not physically handled by the clients. When Darren asks Lynn about Concept 1, she pulls up an image on the slide. As he studies that image and the model on the table, Darren becomes confused again about the basic form of the concept:

[After Lynn changes the PowerPoint slide to show Concept 1, Darren briefly glances over the storyboard, models, and image on the PowerPoint slide.]

Darren: The um, the first – *[Lynn changes the slide to Concept 1.]* Yeah, that one there. Um, are you thinking that, and I guess I'm just having a hard time seeing, is that sphere…is it hollow or are those pie sections that –

Lynn: They are solid.

Darren: Okay. So it actually has the colored sides going in?

Lynn: Yeah, so you have different colors of fabric coming in.

Again, the visuals are conflicting, and the model is not available in a form that is available for manipulation by the client. In this instance, the artifacts (the slide image and the model) actually contribute more to confusion than to understanding.

The artifacts also do not facilitate *Understanding—Exploration/Discovery* (code 1.2), even though the clients attempt to find out more about the materials and construction of the concept as related to its function:

[Max looks up at the PowerPoint slide and then looks at Lynn as he speaks.]

Max: So is that a cushion or is that a…like a piece of cork skin on the outside?

Lynn: Um, probably fabric.

Max: Fabric? Okay.

Lynn: Yeah.

[Darren then tries to add to the conversation and further understand how the concept would be manufactured and function.]

Darren: *[To Max]* It looks like… look at this, like - some of the - final image at the bottom - it looks like it's a tube that does this *[makes a bouncing motion with his hands]* but then there's that foam on the outside that kind of –

Lynn: Well, actually the frame is inside of the plastic, so you can't see the frame outside. Inside is the frame, so when you sit down, you push the frame.
Darren: Okay, got it.

As Darren makes the bouncing motion with his hands, it is evident that some sort of tangible, physical model would aid in exploring the potential functions of the concept. However, Lynn's models are not available to be used as physical elements in the discourse.

The feedback in this presentation was extremely limited. Aside from the clients' comments as they struggle to understand the basic form and function of the concepts, the clients provide Lynn with a minimal positive comment as Darren concludes the session with *"Interesting. […] Thanks."* Lynn's physical models are limited in that they cannot be handled (because they are fragile and/or out of reach) and their form conflicts with the images of the design as presented in the slides and the storyboards. In this session, the artifacts do not facilitate discussion and in fact contribute to confusion, with the consequence of limiting opportunities for evaluative and exploratory discourse.

4.3.2 Mechanical Engineering Final Design Review Presentations

Prop Team: Solid Artifacts, Rich Discourse. In this presentation, the students use a structured approach to present their project, which is a motorized machine capable of lifting and towing a small aircraft. Each student takes a turn talking about various aspects of the design and addressing each of the instructor's questions. They use their prototype to demonstrate proof of operation and a video to demonstrate proof of towing. Upon conclusion of the presentation, the instructor gives the team their final grade for the course. Specific analysis of the discourse using our codebook is presented in the following paragraphs.

As the students and instructor view the video of the prototype lifting and pulling an airplane, the student (Saul) narrates the action and responds to the instructor's (Nelson's) questions:

[Saul and Nelson continue to watch the video.]
Nelson: Oh, and we're a good half inch off the ground?
Saul: *[Points to the video screen.]* And you can see right? It just went off the ground now. And we were waiting for a half-inch off.
Nelson: Clearance is about…what? Three-eighths?
Saul: Um, we did not exactly measure that at that time.
[Brief pause in conversation as Nelson continues to watch the video. Esther, standing behind the computer and thus unable to see the video, then makes a comment.]
Esther: In the video, you'll see him pull it forward and then after a minute, he'll push it back.

The narration combined with the video enables the students to illustrate (code 1.1) the basic functionality of the prop puller. The team also uses the prototype itself, which is sitting on the floor, to demonstrate that the machine is operational and to explain to the instructor that the prop puller does not present a safety hazard:

[Esther demonstrates proof of operation with the prototype. She turns the switch on the prototype to engage the lift motors, allowing the prototype to lift the wedges up and down.]

[As the prototype moves, Mark looks up at the instructor and makes a comment.]
Mark: *[Speaking to Nelson.]* And you can see why we've been biased –
[Esther looks up from the prototype.]
Esther: *[Speaking to Nelson and smiling.]* It's really slow. *[Looking back down at the prototype as she continues to operate it.]*
Mark: Why we weren't really worried about the safety hazard.

As Esther operates the prototype, the instructor begins to explore (code 1.2) by asking questions about features that are not readily visible:

[Esther begins to move the prototype back and forth across the floor as the other teammates watch.]
Nelson: *[Watching Esther move the prototype.]* Did we finish the acceleration ramps in there? I mean, I saw you working on that.
Esther: Yeah. It's just a potentiometer on the board, so you can turn it up or down as you want. *[Turns back to the prototype.]*
Nelson: Okay. Alright.
Esther: And you can change the rate up and down as well, so you can adjust the acceleration.
[Esther turns back to the prototype and continues to run the demonstration.]

Likewise, the students take advantage of the narration opportunity to lead the instructor through the operation of the prop puller. Saul's narration promotes a type of discovery process in that the instructor can both view and hear about the capabilities of the machine as well as ask questions (codes 1.1 and 1.2):

[Nelson and Saul watch the video.]
Nelson: Ah, narrate. Tell me what's happening.
Saul: Ah, so right now the lift motors are working, and um, the back wedge is actually moving towards the device *[points to the wedge on the video]* – lifting the plane up. Um, it should come into contact soon. And we have a closer view when it comes off the ground.
[Camera frame is zoomed out to view more participants.]
Nelson: *[Watching the video.]* And what airplane was this one?
Saul: This was a Piper, six-cylinder.
Nelson: Piper six-cylinder?
Saul: Yes.
[Nelson nods.]

Since the teams would not have the opportunity to make substantial changes before the competition phase, the final design reviews did not result in suggestions for modifications. However, positive evaluations are evident when the instructor asks the team leader for his self-evaluation of the team's work (which is positive) and then gives the students an 'A' for their course grade, contingent on delivery of another artifact—drawings of an electrical diagram to instructor within a week.

Robot Fish Team: Robust Artifacts, Robust Discourse. The prototype designed by this team is a bio-inspired robot with intended use in future research. It is composed of multiple parts that include an electrical system fabricated by the students, as well as other parts ordered from external sources. The code that operates the prototype was developed by an external contractor and was uploaded to the prototype's operating system by the students. Contrary to the structured presentation by the Prop Team, the presentation by this team follows a discussion-like structure from the beginning. The students do not get up and talk about various aspects of the prototype. Rather, they have the instructor (Nelson) and project engineer (Andrew) watch their video (created by the absent student), which is carefully produced and is somewhat "entertaining" and takes up about 50% of the presentation time. The students then discuss changes and reasons for the changes made to the design, and conclude by showing the instructor first-hand that their prototype functions. The presentation concludes with the instructor evaluating the team and giving them a final grade of 'A'.

The video, which the team uses to prove that their robot can actually "swim" and maneuver around objects while submerged, facilitates *Understanding* both in terms of simple illustration (code 1.1) and exploration (code 1.2). First, the video shows a real fish and the robotic fish in order to illustrate that the robot's form is like the actual fish. The instructor (Nelson) verifies which is which, *"That's the real one?"* and confirms the functionality and the environment (code 1.1), already adding in a positive evaluative comment (*"Nice."* code 2.1):

[All participants are watching the video with the exception of Doug, who is watching Nelson.]
Andrew: Nice. [Smiles.]
Nelson: So that's below surface, right? [Doug looks down at the video, then back up at the instructor.]
Joshua: [Looking at the video.] Yes.
Doug: [Looking back down at the video.] Yes.
Yori: Yes.
Nelson: Oh yeah. No waves.
[Brief pause as the participants continue to watch the video, with the exception of Doug, who watches the Nelson.]
Nelson: So, neutral buoyancy is pretty good.
Neal: Mhm.
Doug: Yes.

Using the prototype itself, the students illustrate its functionality as the instructor gains understanding by exploring (code 1.2) through a sort of "cause-and-effect" interaction with the prototype:

[Joshua is holding the prototype and activates the sensors with his hand as Nelson watches.]

Doug: And the IR is a differential-based code – *[Nelson puts his hand up to the right sensor on the prototype.]*

Joshua: *[Putting his hand up to the left sensor.]* Both eyes have to see something.

Doug: Yeah. Both eyes have to see something as a error-checking method. *[Nelson puts his hand in front of the prototype in an effort to activate both sensors and then lowers his hand.]* And beyond that it takes the differential between the two distances and *[Nelson raises his hand to again activate the sensors]* whichever side sees an object closer, it turns away from it so it can turn in both directions.

[Nelson lowers his hand as he continues to watch the prototype as it moves in Joshua's hand.]

Furthermore, as the instructor holds the prototype he asks explorative questions:

[Nelson holds the prototype in his hands as he inspects it.]

Nelson: Wow. How much does it weigh? *[Weighing the prototype in his hands.]*

Joshua: Um, it's over –

Yori: Two pounds. *[Looks up at Joshua.]*

Joshua: Yeah.

[Nelson then closely inspects the prototype. He then tilts the prototype to look at the back of it from the tail-end.]

[Crosstalk]

Joshua: All of our buttons are back there – reset, on…

Nelson: *[Shifting the prototype in his hands*.] Oh, that's not material. *[Shifting the prototype in his hands again.]*

Joshua: We charged it all up -

Nelson: That's the IR sensors.

[Nelson continues to inspect the prototype in his hands.]

Understanding through exploration and discovery also occurred as the instructor and the project engineer viewed the video. At the beginning of the video, the students filmed the prototype as its components moved while still in its preliminary stages of design (i.e., the prototype did not have the chassis or its outer shell, revealing its internal wiring and components).

[It is assumed that all participants are watching the video at this time; however, the camera is zoomed in so that only the video displayed on the laptop screen is visible.]

Andrew: Is this the -

Joshua: This is to test the – *[Points to the computer screen.]*

Andrew: Just "go" mode?

Joshua: Yeah, *[looks up at the instructor and project engineer]* just to see all the servos and waves. *[Looks down at the video on the screen.]*

Nelson: Is everything working fine?

Joshua: *[Pointing to the video.]* This is not the right – the code that was uploaded for that just says, "move all the servos" *[makes small circular motions with his hands as he speaks]* to make sure that…
[Joshua then continues to watch the video.]

In this instance, the instructor notices that all of servo-motors are turning all of the components of the prototype at the same time. The instructor questions this as a malfunction of the prototype, but as Joshua explains why all components are moving at once, the instructor shifts his understanding from interpreting the prototype as having an operational error to that of a prototype that is undergoing a performance test. Because there is a shift in the instructor's understanding that is informed by further explanation and inquiry, this instance has been coded as gaining understanding through exploration and discovery (code 1.2).

In contrast to the PT scenario, the instructor provided evaluative comments throughout the session with the Robot Fish Team. As they watch the robotic fish in the video, the instructor and the project engineer are obviously impressed by its maneuverability:
[It is assumed that all participants are watching the video. The camera is zoomed in so that only Joshua and the video may be shown in the frame.]
Nelson: There it is on its side. It rights itself well.

[As the participants watch the video, the turning movement of the prototype is captured, allowing Nelson and Andrew to view its maneuvering capabilities.]
Andrew: Wow.
Nelson: It's turning the other way.

Again, a similar instance occurs as the participants continue to watch the video. However, in this case the project engineer and instructor comment on the artifact itself:
[The participants continue to watch the video until it concludes.]
Andrew: Very good video.
Nelson: Yeah, very good video, actually. All right. Continue.
[Nelson then directs the students to continue on in their presentation.]

These positive evaluations are interesting in that in responding positively to the video artifact that the students created, the instructor and project engineer are also commenting on the entire design process that the students went through. This shifts the conversation from evaluating the design itself to evaluating how the design is being communicated.

Interestingly, the only negative evaluations come from the students critiquing their own design as *"not accurate enough,"* but the response from the instructor took this as a positive that they recognized the limitation, continuing to look at the robot moving in Joshua's hand and commenting only *"Okay. Very good."* The presentation is concluded by a satisfied instructor stating *"So, by our algorithm, that gives you an A. All of you—your whole team. Very good."*

In this presentation, the instructor and the project engineer were able to physically interact with a prototype, which led to understanding through both illustration/explanation and exploration/discovery. They also responded with positive evaluations to seeing the richly crafted video that showcased the functionality of the prototype. This communication artifact was so rich, in fact, that the instructor and the project engineer commented on the artifact itself. The richness and increased interaction with artifacts in this scenario seemed to facilitate increased discourse and more frequent turn-taking.

Cap Team: Incomplete artifacts, Aborted Discourse. The prototype designed by this team is a jar opener for scientists to use to open jars that contain volatile substances and have the potential to explode upon contents reacting with the air. The prototype is made out of metal parts fabricated by the team and other parts ordered through an external fabricator. The students also designed the electrical components that run the prototype; however, the entire prototype is controlled by a computer program. Unlike the other two ME teams, this team cannot answer the standard questions for the FDR. Their prototype is not fully functional, nor fully assembled. Upon learning these downfalls in the students' progress, the instructor quickly ends the presentation and tells the team to revisit their project – otherwise they will fail the course. A second attempt for this team to complete the FDR was not recorded, nor do we know if they even tried to schedule a second attempt. Specific analysis of the discourse using our codebook is presented in the following paragraphs.

Although the team has brought in their prototype, it is not working at the time of the review. In an attempt to understand why, the instructor asks a few basic questions as he examines the prototype with the students:

[The student team stands huddled around the prototype. Nelson sits at a desk that cannot be seen in the camera frame.]

Nelson: You need batteries, right? You have insufficient batteries?

Jeffrey: Well, it was working for a time last night, but then we lost power with the battery that we had.

Nelson: That little battery right there?

Jeffrey: [Pointing to the larger battery on the counter.] No, that bigger battery… [Miles and Mason tap the battery on the counter.]

[Miles then continues to explain the situation with the batteries.]

Rather than questioning the prototype itself, the instructor probes the team to provide more information as to why they could not obtain a sufficient power source for their prototype:

[Students are still standing around the prototype as Nelson continues to sit at the table.]

Nelson: So, why don't we have more batteries?

Mason: Well, we tried to go get the ones that we needed, and we couldn't find them last night.

Nelson: Why were we trying to get them last night…as opposed to…in the last 3 months?

[Mason shakes his head and Brody joins in the conversation in an attempt to answer the instructor's question.]

The instructor is trying to gain further understanding about why the prototype is not fully functional by exploring and asking questions. Since the artifact does not, or cannot, play an active role in communicating features of the concept, the instructor relies on discourse to gather his information. In this case, the absence of a functioning artifact prompts further discussion of the process that has led to this point rather than feedback on the prototype itself.

This scenario was brief, and only a few evaluative comments occurred as the students and instructor simply stand around the non-functioning prototype. One of the two positive evaluative comments came from one of the students, who seemed to be trying to shed some positive light in the midst of the malfunctions, *"The machining is good, like, um …",* and the other came from a perhaps sarcastic instructor near the end of the review:

[Nelson is now standing at the prototype with the students.]

Nelson: You must be close if you're only short of a battery.

Negative comments occur as the students present the prototype and must admit to its incomplete status:

[Students are standing around the prototype.]

Mason: Our project. Ah, in terms of assembly, it is not fully assembled. We do not have the force sensors included because while testing last night they were giving us completely, um, unreliable data. We couldn't get them to give us a number that, that was similar at all. It kept jumping around a lot. So we, um, just left them off because they weren't functioning correctly. And we also don't have sufficient power sources to power everything at one time. So it's also not fully assembled in that way.

[Students are still standing around the prototype.]

Mason: And in terms of functionality, um, the machining is good, like, um, but the lifting motor and the rotating motor will not lift or rotate. Um, they kind of just vibrate in place. We had them, we had them both working at one – at – in the past, but right now, they are not functioning.

Disappointed, the instructor ends the session by stating that the team is at risk of failing because the prototype is not fully assembled and not fully functional. However, in light of the team presenting an incomplete prototype, the instructor offers some encouragement by allowing the team the option of re-presenting their prototype at a later time. Interestingly, the team leader's reaction seems almost defensive, as he rolls his eyes and shakes his head.

5. Discussion and Conclusions

The discourse analysis across the design reviews and contexts reflects both the complexity and the nuanced nature of expert-student dialogue in design learning contexts. Although we often refer to this work as "mentoring," the range of specific language practices experts invoke at different times in response to different student needs highlights the linguistically rich interactions that occur as language mediates design learning. The discourse analysis presented here complements similar types of analysis conducted on the same larger data set, including:

- explorations of practical versus conceptual reasoning embedded within student design talk in the form of *semantic gravity* (Wolmarans, 2014);
- student designers' abductive reasoning of issues raised by deductive analysis, or *generative sensing* (Dong, Garbuio, & Lovallo, 2014);
- evaluating student design quality through creativity, aesthetics, and functionality (Christensen & Ball, 2014); and
- *designerly ways of being*, or how students position themselves throughout the design process as designer, user, or both (Tenenberg, Socha, & Roth, 2014).

Evidence of design learning may be revealed through mechanisms such as talk and positioning as well as more cognitive-related functions such as creativity and generative sensing. Such analyses, taken as a whole, reflect the ways in which the language of design education is not simply transactional, intended to convey information, but generative and reflective as it structures knowing, meaning, and doing.

At the same time, this analysis suggests that design learning is mediated by more than language use alone. The artifact analysis reflects the interdependence of word and designed object as experts engage students in the process of design. This integrated analysis demonstrates at least two possible ways in which artifacts intersect with language to mediate the activity of design learning in design reviews across both mechanical engineering and industrial design contexts.

First, robust artifacts can come in many forms, including slide presentations, videos, rough models of designs made of materials such as paper and foam core, functioning prototypes, and storyboards. They are engaging (as exemplified in the Robot Fish Team video), or easily interacted with (as in Adam's models and PT's prototype). In such cases, the discourse patterns tended to be balanced across an array of speech acts that engaged both the design itself and the students' learning about the design (e.g. through reflections or extension of the work). Artifacts that contribute weakly to discourse, in contrast, are artifacts that don't work (as in the Cap Team example), that conflict with other artifacts (as in Lynn's presentation), and that aren't accessible or easily handled and explored (for example Lynn's flimsy and hidden models, and Cap Team's inoperable prototype). In these cases, speech acts were dominated by Clarify and Understand as experts struggled to come to terms with the details of the design itself, with little opportunity to engage productively in discussions about how to revise, enhance, or extend the design. In the case of the Cap Team, because the FDR was also a critical evaluation point, the speech acts also included a preponderance of evaluative comments and advice about final steps needed to simply pass the course.

It is notable here that in the Client and Final Design Reviews both the models and the visuals (slides, videos) worked together to mediate the discussion among participants about the design concepts and features. In fact, as indicated by the quantitative data showing varied and dense speech acts in the ID First and Second Reviews, robust artifacts need not be models; sketches and drawings, when serving as points of collaborative work, can generate substantial discourse between experts and students that can be rich sites for learning.

Second, robust artifacts facilitate in-depth understanding that goes beyond the level of explanation and promotes exploration and discovery, often involving collaborative discussions by multiple participants (examples include the client participation in Adam's review, and the project engineer's and instructor's enthusiasm in the Robot Fish Team review). Within the ID Client Reviews and ME Final Design Reviews, reviews in which the artifacts were weak did not result in rich discussions and often stalled at the level of illustrating and explaining (and sometimes failed at that task, as in the Cap Team review). Instructors and clients appeared to be less able and less willing to contribute meaningful evaluation of weak artifacts in the ID context, though as noted above, evaluation was the central goal of the ME final review and thus present of necessity. The quality of the artifacts, both independently and in tandem when multiple types of artifacts are present, played a role in determining both which features of the design were discussed and how they were discussed. That is, artifacts can draw participants into richer, more complex, and more generative discussion about design development. In all cases, the more robust artifacts corresponded to a higher density of expert speech acts, suggesting a more dialogic exchange between experts and students centered on the "doing" of design.

In conclusion, perhaps the role of artifacts and their impact on design discourse is best viewed as a continuum in which artifacts that capture student concepts promote discourse and artifacts that do not capture student concepts impede discourse. That is, artifacts that do not capture student concepts shift discourse from the goal of evaluating to the goal of trying to understand why the breakdown is occurring, while artifacts that usefully embody the designers' ideas and, importantly, can be shared and explored between experts and novices, coincide with rich discourse about the design itself, and thus appear to be a key tool in the learning that occurs in these activity systems.

The mediating role of artifacts in these contexts also reflects their broader role in negotiating the power dynamics and social relationships between experts and students. As such, they invoke Winner's "theory of technological politics" (Winner, 1999), which provides a way to explore how design artifacts shape and are shaped by the larger socio-cultural relationships. Winner's approach illuminates both how technologies structure communities and how they may invoke specific political structures. Objects in the design reviews, such as student-developed models, prototypes, and presentations, are thus not passive objects under reviews, but technological artifacts that structure and are structured by the social relationships and power dynamics among the students and mentors. As such, like language, these artifacts-in-use help structure both the participants' identities and the nature of design. In the cases studied here, these politics emerge in the ways in which for example, concept drawings function as a site of shared work in the early ID reviews, or expert proximity to and engagement with prototypes in the ID CRs created a similar sense of shared, collaborative work. The absence of that collaboration, and a corresponding shift in power dynamics, was particularly evident in Lynn's CR, in which she not only maintained close control over her prototypes, but hid them from view, and thus resisted the collaborative dynamic seen in Adam's CR.

As Winner's analysis suggests, neither the artifacts themselves nor the ways in which they are manipulated by the participants are neutral. Instead the nature of the artifacts (robust or fragile, detailed or vague, functional or conceptual) enable or hinder specific kinds of relationships between experts and students. At the same time, the artifacts are not deterministic, and the ways in which the designers do, or don't, share artifacts, as well as the ways in which experts choose (or not) to engage with them, reflects both the power dynamic and modes of becoming a professional in one's field. In the cases considered here, for example, the uses of the artifacts suggest markedly different beliefs about both design and design learning between the ME and ID courses. While the ID students have worked throughout the undergraduate curriculum with iterative artifact designs and critiques, the ME students encounter this type of design process in more limited ways. These practices indicate a distinct difference between how the disciplines construct the nature of design and design artifacts, and by extension what it means to be a design expert.

6. Implications for Design Education

In exploring discourse and artifacts as tools mediating design learning activity systems, the cases described in this paper highlight the ways in which language and artifacts intersect, with artifacts serving as a generative tool for rich discourse. In particular, the artifacts often functioned as sites for both understanding and evaluation, creating important nuances in speech acts that helped the students more fully develop their design ideas. Across these cases, richer artifact use, in which students and experts engaged with objects that provided meaningful representations of the design ideas, corresponded not only to richer discourse, but also corresponded to higher team performance. However, we do not posit causality here; in fact, it may be the case that the higher-performing teams were better able to produce useful artifacts and were more open to using those artifacts as a site of collaboration.

Despite the preliminary nature of our findings across a limited set of cases, the links between artifacts, discourse, and design quality suggest potential strategies for design educators, particularly in engineering where prototyping often occurs quite late in the design process. In particular, reflecting on practices in disciplines such as industrial design, engineering design mentors should consider:

- teaching students to develop artifacts early, including sketches as well as preliminary models.
- teaching students to present and use these artifacts to explore design ideas with one another and with expert mentors. Such teaching is critical to helping students understand that artifacts are not passive representations created after the "real" work is done, but rather integral elements in the process of discussing and developing design ideas.

- actively engaging with student artifacts as sites for both exploring and extending students' design practices. Design reviews in which experts and students dialogue with and around sketches, models, and prototypes appear to be particularly strong sites of discourse and learning.

Even as more work needs to be done to better understand how artifacts function in design learning, the preliminary work presented here suggests they play a critical role in triggering meaningful discourse between experts and student learners.

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Appendix A: Expert Speech Acts in All ID Reviews

Review*	1R Lynn	1R Todd	2R Adam	2R Alice	2R Sheryl	CR Addison	CR Adam	CR Alice	CR Esther	CR Lynn	CR Sheryl	CR Todd	LLR Addison	LLR Esther	LLR Sheryl	LLR Todd	FR Addison	FR Alice	FR Adam	FR Esther	FR Sheryl	FR Todd
Acknow. Enthusiasm	4.7%	3.4%	3.9%	4.8%	6.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Advise	41.9%	50.0%	64.7%	43.3%	55.2%	11.1%	0.0%	0.0%	18.2%	0.0%	0.0%	12.5%	57.9%	36.1%	67.9%	59.5%	0.0%	0.0%	0.0%	12.5%	0.0%	0.0%
Challenge	0.8%	0.0%	0.0%	1.0%	0.0%	11.1%	13.3%	0.0%	0.0%	0.0%	12.5%	25.0%	2.6%	1.6%	0.0%	2.7%	11.1%	0.0%	0.0%	0.0%	0.0%	10.0%
Clarify	2.3%	6.8%	0.0%	4.8%	0.0%	11.1%	13.3%	0.0%	27.3%	42.9%	12.5%	25.0%	0.0%	14.8%	1.2%	5.4%	22.2%	20.0%	16.7%	37.5%	25.0%	20.0%
Command	0.0%	1.1%	0.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	0.0%	1.6%	0.0%	0.0%	11.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Demonst. Expertise	7.8%	6.8%	5.9%	14.4%	10.3%	22.2%	13.3%	11.1%	9.1%	0.0%	0.0%	0.0%	7.9%	14.8%	10.7%	8.1%	0.0%	0.0%	8.3%	0.0%	0.0%	0.0%
Evaluate	25.6%	19.3%	17.6%	16.3%	24.1%	22.2%	26.7%	44.4%	9.1%	0.0%	0.0%	12.5%	5.3%	1.6%	6.0%	0.0%	33.3%	10.0%	33.3%	12.5%	37.5%	30.0%
Express Satisfact.	0.0%	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.3%	3.3%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Extend	0.0%	2.3%	0.0%	2.9%	0.0%	11.1%	0.0%	11.1%	9.1%	0.0%	0.0%	12.5%	0.0%	1.6%	0.0%	0.0%	0.0%	10.0%	0.0%	25.0%	0.0%	0.0%
Promote Reflection	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Protect	0.0%	0.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.3%	1.6%	0.0%	2.7%	0.0%	0.0%	8.3%	0.0%	0.0%	0.0%
Understand	17.1%	9.1%	5.9%	11.5%	3.4%	11.1%	33.3%	33.3%	27.3%	57.1%	75.0%	0.0%	10.5%	23.0%	11.9%	21.6%	22.2%	60.0%	33.3%	12.5%	37.5%	40.0%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
% Quest	4.7%	13.6%	3.9%	11.5%	3.4%	33.3%	40.0%	33.3%	45.5%	57.1%	75.0%	37.5%	18.4%	31.1%	14.3%	21.6%	33.3%	60.0%	25.0%	25.0%	25.0%	40.0%
Density	5.0	4.4	3.2	5.0	5.8	1.5	2.1	1.5	2.2	1.4	1.3	1.3	3.5	5.5	3.8	4.1	1.5	1.4	1.7	1.1	1.1	2.0

*1R = First Review; 2R = Second Review; CR = Client Review; LLR = Looks Like Review; and FR = Final Review