Disciplinary Discourse in Design Reviews: Industrial Design and Mechanical Engineering Courses

Micah Lande & James Oplinger

Arizona State University, Mesa, AZ, USA
{ Micah.Lande, James.Oplinger } @asu.edu

Abstract: *An increase in focus on design thinking in the engineering community and design education has led to innovative outcomes. A part of the design thinking education comes from the goals and teaching methods of instructors. From a given dataset of design reviews two different courses were evaluated: industrial design and mechanical engineering. This work analyzes how instructor interactions with individuals or teams fulfill course outcomes. From a discussion of the data analysis it is suggested that industrial designers focus on the passion of the product design while mechanical engineers focus on the functionality and completeness of the design. The ideological approach in each disciplinary course merge ideology of courses such as industrial design into course such as mechanical engineering. The design thinking push hopes to build future innovators, preparing students for the open-endedness of real world problems.*

Keywords: *design reviews, design coaching, designerly thinking, engineering thinking*

1. Introduction

Innovation is a difficult challenge. Today, it often takes many players from many areas working together to create something new. Multidisciplinary perspectives of engineering, business and design stitched together (Feland, Cockayne et al. 2004), can achieve design innovation via a comprehensive blend of feasibility, viability and desirability. This can be present in cross-functional teams (Schar 2011) within an established organizational culture as well as in the *T-shaped* individual with depth in one disciplinary field and breadth across others (Kelley and Littman 2005). Along the way, competing voices and values often surface from groups and individuals based on their disciplinary and epistemic roots.

Design thinking has become increasingly popular parlance in the engineering design community as well as in design education (Dym, Agogino et al. 2005) and business circles (Kelley and Littman 2001; Nussbaum 2004; Brown 2005; Kelley and Littman 2005; Brown 2008; Brown 2009; Martin 2009). This design thinking approach has become useful as a differentiator for schools (Nussbaum 2009) and companies (Borden, Breen et al. 2008). For many, this human-centered design approach results in innovative and novel outcomes, sometimes leading to market success. To focus on the resulting product, service or experience, however, is oftentimes a near-sighted approach; it neglects the process, the people involved and their pathways towards a realized and refined solution. The commercial and tangible outputs of engineering design can be evident by sales (Feland 2005) or industry awards (Petersen 2010). For the underlying steps by which a product or service was created, however, not much foundational understanding exists about how these outcomes are delivered, i.e., the actual engineering design process by which such innovation is created. More importantly, there is also limited knowledge or experience in how to coach productive teams (Reich, Ullmann et al. 2009) to arrive at innovative and impactful solutions.

Examples of success by design pervade, often in the form of Apple as an exemplar of innovative products (Thomke and Feinberg 2009) or people (Isaacson 2011). Less has been captured of how these designed objects come to be other than anecdotes relating to management decisions (Levy 2011). Snapshots of design activity (Cross, Dorst et al. 1992; Lloyd, McDonnell et al. 2007; McDonnell and Lloyd 2009) and lab experiments (Atman, Chimka et al. 1999) are present but capture segmented moments through necessarily artificial design task constructs. Facets of design thinking (Dym, Agogino et al. 2005) and engineering rhetoric (Robinson 1998) have been examined separately; we are curious how ideas are both important to problem formulation and problem solution.

2. Research Questions

Design is a discourse whose application has an evident outcome that creates a value proposition, however, the activities of those engaged in it from concept to the fruition of implementation are not well documented. How do designers and engineers do what they do, and how do they learn from such activities? How we teach or coach engineering, design and innovation can reflect the epistemic values of these disciplines. Given a shared data set (Adams & Siddiqui, 2013), how do disciplines like mechanical engineering design, industrial design, etc. approach problem framing and finding, and solution finding?

How do these traditions practice in similar and different ways? We explored evidence of *designerly* ways of knowing-doing-acting and *engineering* ways of knowing-doing-acting in the data set. The undergraduate / capstone Industrial Design and Mechanical Engineering cohorts are most relevant as a direct cross-case comparison. We sought to identify strategies people use (with a first focus on the industrial designer and engineering groups). We were also curious how these approaches are refined over time in the courses. Our plan has been to perform an emergent thematic analysis of the recorded activities. We have been most interested in the differences in pedagogical approach and the role of the instructor is these design reviews through disciplinary discourse. Our primary research questions are:

> *RQ1.* How do mechanical engineering design and industrial design disciplines approach problem framing and finding, and solution finding?
>
> *RQ2.* What roles do instructors of different disciplines fulfill?

By fulfilling these research questions we hope to get a sense of how different design courses solve problems. The hope is to discover ways on which to possibly improve existing design courses by integrating methods of teaching.

3. Theoretical Framework

As a research basis, this approach has theoretical roots in design thinking (Cross 1982, Dym et. al. 2005), engineering thinking (Robinson 1998, Cardella 2010), their intersection (Feland et. al. 2004, Schar 2011), and coaching (Riech et. Al. 2009). It borrows from the snapshots of design activity (Cross, Dorst et al. 1992; Lloyd, McDonnell et al. 2007; McDonnell and Lloyd 2009) and lab experiments (Atman, Chimka et al. 1999; Carrisoa 2002) in the analysis of design process steps. The research also looks into the differences between different types of design thinkers from a science (engineering) or art (design) basis (Klinker and Alexis 2009).

This also builds on previous work studying the mechanical engineering graduate students doing design work as under a framework of *Ambidextrous Mindsets for Innovation* (Lande 2012a), below in Figure 1, and previous engagements with DTRS and DTRS-like collaborative data set analyses (Cardella & Lande 2007; Lande 2010, Lande 2012b).

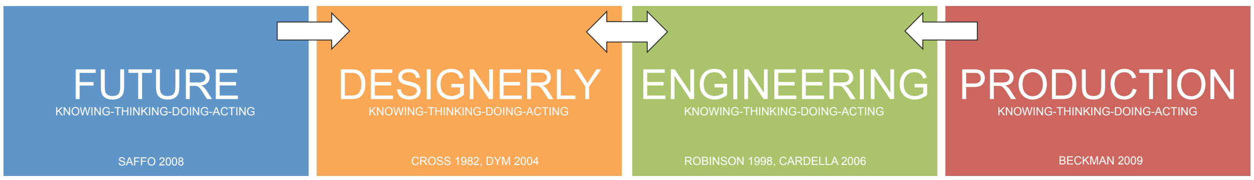

Figure 1. Ambidextrous Mindsets for Innovation relating ways of knowing-doing-acting among future, designerly, engineering & production ways of thinking (Lande 2012a).

3.1 *Designing and Engineering*

Humanity has been designing and engineering artifacts much longer than there has been language to describe such activity. Designers and Engineers are labels adopted in the last century to describe specialized practice performed by professionals engaged in industry. Such connotations are readily used but their precise meanings shift, dependent on context and discipline. We are concerned herein particularly with characterizing a distinction within the field of mechanical engineering, specifically where these labels may also be thought of descriptively as design engineering and engineering design.

3.2 *Historic Traditions*

Development and education of designers and engineers has been the province of different disciplinary traditions. The jobs of engineers grew out of war-building and civil infrastructure building. Designers have emerged from either a science-based methods focus or an arts-based tradition (Klinker and Alexis 2009). The collision of these two roles emanates from the contrast between manufacturing and commerce, the rise of material technology (like plastics to make unorthodox shapes), and computer-supported collaborative practice.

3.3 *Labels*

Design and Engineering are labels for individuals and groups that undertake the acts of designing and engineering. Daly, Adams, et al. (2012) explored tenets of design activity that are displayed in professional fields as far afield as dance to baking to electrical engineering. For purposes of this research, the focus will be on what discourse exists relevant to engineering, engineering design and mechanical engineering design. Design and Engineering are sometimes used interchangeably or singularly distinct but have not yet been compared and contrasted.

3.4 *More Than Problem Solving*

Cross (1982) described *designerly ways of knowing, doing and acting* with user empathy at its core. Empathy has been invoked as core to user-centered design (Norman and Draper 1986; Faste 1987; Patnaik and Becker 1999; Norman 2002; Laurel 2003; Suri and Howard 2006; Patnaik and Mortensen 2009). Dym, Agogino et al. (2005) summarized design thinking by describing core aspects as divergent and convergent (Eris 2004), about the design of systems (involving uncertainty and estimation) (Stacey and Eckert 2003; Cardella 2007; Cardella and Lande 2007; Carleton, Cockayne et al. 2008; Cardella 2010), design decisions, and as aspects of team-based activity (Tang and Leifer 1988; Baya and Leifer 1994; Brereton 1999; Leifer, Culpepper et al. 2004; Sonalkar, Jung et al. 2010; Lande, Sonalkar et al. 2012).

Problem solving has often been a part of the proffered definition for design actions but it is often only part of a larger context. Gasson (2007) enumerated design as 1) problem setting, 2) problem solving, 3) situated learning and 4) functional analysis. Cross (1995) is inclusive about engineering design activities going after ill-defined problems. Visser (2006) combined problem solving and ill-defined problems to equate to more than problem solving alone. Thomas and Carroll (1979) called design a problem approach unique to other forms of problem solving. Some also commented that design cannot be comprehended as problem solving (Stolterman 1992; Winograd, Bennett et al. 1996) or is a richer concept than problem solving (Nelson and Stolterman 2003).

Engineering has been described as a rhetoric strategy for problem solving and implementation (Robinson 1998) invoking specific language for discourse (Bucciarelli 2009) and mathematical thinking (Cardella 2007).

3.5 *Specialized Roles*

New engineers face *siloed* work environments where roles are specialized and responsibilities are shared across large organizations (Schar and Lande 2012). No one person works on a complete project – start to finish. There are many barriers to discourse within the manager-employee structure and dynamic (Brunhaver, Korte et al. 2010).

3.6 *Capstone Design Education*

Design is often taught as a series of rigid tools, methods and processes to help do engineering problem solving. Design is sometimes used as a gateway to engineering content knowledge and often used as the structure for senior engineering capstone courses (Todd, Magleby et al. 1995). Capstone design courses include engineers who are asked to synthesize their prior engineering content knowledge. Their engineering challenge is often a system that focuses on the technology and absent the people aspect of the system. Project Based Learning (Prince and Felder 2006) focuses pedagogical efforts on open-ended, authentic problem solving. The bases of many capstone engineering design courses are engineering challenges done on behalf of a third-party, either as a sponsor or end-user.

3.7 *Studies of Design Activities*

Previous studies (Atman 2005, Atman 2003) have characterized the relative design processes of college students in their freshman and senior years, design educators and practicing designers.

Based on individuals constrained (both by time and scope of problem) in a lab design activity, Atman et al. (2005, 2003) were able to identify and describe differences in design process practice, namely, time on problem definition, chronology of process, and iterative steps.
Additional work (Adams 2001) explicitly captures the design steps and processes of Atman's design experiments, expressly highlighting iteration as behavior of experts.

4. Methods

For the research that follows information from the industrial design junior level course and the mechanical engineering course was studied. We began with reviewing the course materials provided, mainly the course syllabus, for evidence of the community of practice attached to the discipline covered including the course objectives and goals. Transcripts of each design review were studied focusing on questions and comments asked or made by the instructor. From each syllabus the plan was to get a general understanding of the course. Notes were made of each of the course goals and expectations the instructor had placed. Should the syllabus also include expectations students should have of the instructor they will also be recorded. Any other significant notes or differences between syllabi will be taken into account as well. Once a general understanding of the course was made the transcripts of each design review were analyzed. Questions and comments made by the instructor are singled out and inspected. Questions that we asked when reviewing questions are:

- What type of question was asked? Convergent or divergent in nature?
- How do the students respond? Are there follow up questions?
- What patterns exist within a single review? within reviews of different groups/individuals?
- How do the questions reflect whether students have met or are progressing towards course goals or not?

Methods and questions from different disciplines are then compared. The data will then be reviewed for any patterns or uniqueness between disciplines. From this we can determine how design thinking is demonstrated within different groups of students.

From the design review data the syllabi and design reviews with the instructor(s) were taken. From the junior industrial design course this included a first review, second review, and "look like review." In the mechanical engineering course this included a concept design review and a final review. Table 1 shows a complete list of material utilized.

Table 1. List of transcripts used from dataset

ID-Junior	Syllabus	ME	Syllabus
ID-Junior	First Review Lynn	ME	Concept Design Review Cap Team
ID-Junior	First Review Todd	ME	Concept Design Review Robot Fish Team
ID-Junior	Second Review Adam	ME	Concept Design Review Prop Team
ID-Junior	Second Review Alice	ME	Final Design Review Cap Team
ID-Junior	Second Review Sheryl	ME	Final Design Review Robot Fish Team Part 1
ID-Junior	"Look Like" Review Addison	ME	Final Design Review Robot Fish Team Part 2
ID-Junior	"Look Like" Review Esther	ME	Final Design Review Prop Team Part 1
ID-Junior	"Look Like" Review Sheryl	ME	Final Design Review Prop Team Part 2
ID-Junior	"Look Like" Review Todd		

5. Junior Industrial Design Course

Throughout the series of design reviews in the Junior-level Industrial Design course, the instructor serves in a role as coach to help students discover and review their own work through leading questions that model a guided inquiry pattern. Summaries of selected design reviews follow that try to describe the question asking patterns within. The course syllabus, a first review, a second review, and a "look like" review were analyzed.

5.1 *Syllabus and Learning Outcomes*

Instructors listed goals and expectations for the course within the syllabus. For the junior industrial design course, the goals expectations for the industrial design course are based off of the senior level course and are presented as:

a) *helping students prepare to enter Industrial Design;*
b) *creations in group design projects that are based upon D-search [note: versus "research"], aesthetically refined, functionally improved, and designed with production and the user in mind;*
c) *gain a basic understanding of D-search;*
d) *control of advanced computer modeling to be able to model complex forms accurately;*
e) *mastery of Photoshop rendering.*

The espoused purpose of the course is to socialize students into industrial design, its ways of working, and technical proficiency in modeling and rendering tools.

Industrial design students are given a design brief for the junior level industrial design course, and instead of a syllabus a senior level course syllabus was given as an example of similar expectations. After the instructor's expectations a list of expectations and rules for the design studio were shared. Included with the example syllabus were the design brief specifications on project positioning, design scope, and goals. The positioning specifications give additional detail where the designed furniture will be used. The scope details size and shape options, as well as possible and suggested pieces. The final part of the design brief states the schedule specifications of the course.

5.2 *First Design Review*

During the first design review the students meet with the instructor independently at the industrial design studio. They take this time to go over early concepts and sketches the student shares. At the end the instructor asks the student to pick five designs to develop further. The Industrial Design instructor makes suggestions ("So maybe you could even hang these on some arm comes off the wall or something?") but leaves it open for the student to make the decision. The Industrial Design instructor helps students visualize the setting of their designs:

> *This is nice and simple. It makes it really, really nice, so, and I don't-[clears throat] I wish I could, I could say which ones-I, I don't wanna diminish what you feel passionate about, but that's what's gonna-the passion you have for something is gonna come out in your design. And, actually, actually, these Hershey Kisses is very nice, very nice, and extremely simple. And look at what you could do with fabrics. That's almost like something you find in nature. So to me, something that's like a, it's like a beanbag, but*

it's not, but make it to where it's just a-you come up into an office room and you've got four or five of these things and it's just so inviting and so neat. -Gary

Case: Lynn's First Design Review

The instructor begins with the goal at the end of the review and some basic reminders of the project. The instructor asks many questions on positioning and functionality of the designs. He often provides feedback and suggestions in the form of questions, leaving it open ended. The instructor also notes what may be challenging for the student, and assures that the student realizes the challenge. He also lists questions that the company is going to ask the student as a designer. Near end of the review the instructor asks what ideas the student wants to choose as safe ideas and which ones as passionate ideas. When referring to the student's more ambiguous design the instructor suggests including a graphic showing how to sit on the chair. Throughout the discussion the instructor tried to create a scenario for each design the student had. He notes how much he likes the designs and how good the concepts are. He also made many suggestions on possible materials and design choices. Throughout a majority of the review the instructor was leading the student. (1-ID-jr-FirstReview-Lynn).

Case: Todd's First Design Review

The student initially leads with a brief explanation of some of his designs. The instructor asks if one design is fixed and only an illusion of moveable. The instructor includes questions that force the student to the next level, such as "If you were the designer for one of those other kinda traditional ottomans what would the next level be…it's color. It's form. It's dynamics" (1-ID-jr-FirstReview-Todd, page 4). Similar to Liang's review, the instructor asks for safe designs and passionate designs from the student. The instructor also asks for design clarification on material choice and views. The instruct comments on designs that he thinks are "fun" or different (Figure 2). As with the other student he also lists off questions to expect from the sponsoring company. The instructor closes off with mentioning "'Cause, you know, you need to be passionate about these things…" (1-ID-jr-FirstReview-Todd, page 15). As with the other student the instructor remains relatively positive about the sketch ideas. The instructor also notes when some processes may be too expensive to venture. Similar with the other review the instructor leads a majority of the review (1-ID-jr-FirstReview-Todd).

5.2 *Second Design Review*

In the second design review the students meet once again with the instructor, individually in a work space. At this point the students have had time to flesh out their designs more. After this review the students are expected to have chosen three designs from the original five. These three designs will be shown to the clients in a client review. The instructor prods and asks clarifying questions. The tone is one of inquisitiveness and curiosity.

Case: Adam's Second Design Review

The second design review involved Alex describing his three design choices in great detail. The instructor gives some possible ideas on how one design may end up. The instructor sticks to his regular positive attitude, showing he likes a certain concept. When asking for size clarification the he first asks "…didn't you say it had to be 15 inches high?" and clarifies, "Well, I said—they gave you a range, though" (2-ID-jr-SecondReview-Adam, page 5). The instructor once again asks for at least one passionate idea and a safe idea. The instructor also mentions how important it is to pace yourself through the project. It should be noted that while the instructor is still relatively positive there is a more serious notion in his decisions (2-ID-jr-SecondReview-Adam).

Case: Alice's Second Design Review

The instructor begins asking how the seat in the first design are intended. He also asks if there is something that can be done to add another function to the seats, indicating specific areas of the design that could be modified. In this review the instructor is asking more about what materials the student is planning on using. The instructor maintains his enthusiasm for the designs the student uses as seen here, "I love this just the fact it is open and that's – to me, that's the – you got this energy" (2-ID-jr-SecondReview-Alice, page 7). Despite his enthusiasm the instructor does ask for clarifications on design ideas and notes issues that may occur. The instructor then offers this solution to the student:

> *Develop this to where you think, "Well, you know what? I, I – the, the – this, I've lost the essence of what I wanted to do 'cause I've gotta still make it the dimensional." Ah, and then you can say, "Well, then if that's the case, then I'll switch to something, a little safe" (2-ID-jr-SecondReview-Alice, page 13).*

Overall the instructor maintains that he is impressed with the student's work and looks forward to the designs (2-ID-jr-SecondReview-Alice).

Case: Sheryl's Second Design Review

In the last section of Sarah's design review focuses on her third design and how she plans on choosing which ones to develop. The instructor indicates that he is curious about what materials she plans on using. When the student is struggling to find a solution the instructor offers one:

> *But keep it simple. Keep it ergonomic. Keep it-structured out of wood. And then I can have 'em do it-if you'd like to do this, if you would show this what if you were dealing with a two and a half inch by two and a half sections of upholstery? Which could be neat in itself, you know? And maybe your handle is no longer up here, and it-put a support down here actually is kind of a handle as you grab it- -Gary*

After giving his solution the instructor asks "Which would you rather develop?" (2-ID-jr-SecondReview-Sheryl, page 4). At this point in the design process the instructor does note that scaling the product may be an issue. Ultimately, he leaves it up to the student, saying "You're the designer. Which, which do you think?" (2-ID-jr-SecondReview-Sherl, page 4). During the presentation the instructor mentions that unique ideas are important, even if only part of them are used (2-ID-jr-SecondReview-Sheryl).

5.3 *"Look Like" Review*

The "look like" review is the final review with the instructor before the final client review. These reviews took place in a computer lab while other students were working on projects. Here students show full-scale mock-ups of what they plan the final design to be. This design will be used in their final presentation to the stakeholders. Again, the instructor coaches students to clarify and advance their concepts and ideas on their own discovery while reminding there is a short timeline still available.

Case: Addison's "Look Like" Review

During Adriana's review she shows the instructor a 3D model of the final product. The instructor appears pleased and asks to see the first model that inspired this model. When the student is wondering what material to use the instructor first prods with "How thick are you wanting this back to be?" (4-ID-jr-LookLikeReview-Addison, page 4). Then, instead of answering for the student he now asks what she thinks the material should be. Though the instructor is still open to the student's innovation, he does maintain that the project must be finished by the deadline (4-ID-jr-LookLikeReview-Addison).

Case: Esther's "Look Like" Review

The instructor begins by asking "…there's two different seating effects [or positions]?" (4-ID-jr-LookLikeReview-Esther, page 1). He also asks if there is a rocking feature or if that would make it unstable. The instructor asks about planned materials, design specifics, and the location of parts. He also asks if the clients liked the design choices the student had made. One of the last things he asks is how the student plans to prototype their solution, offering several possibilities. The instructor also reminds the student how critical the next two weeks of the project are and to "Stop and make a decision" (4-ID-jr-LookLikeReview-Esther, page 9).

Case: Sheryl's "Look Like" Review

The instructor starts off asking how the student plans on building the project. He also asks how the telescoping function of the furniture design is going to work. The instructor asks student to have some ideas for how to handle a design element, but to leave it for the company to decide:

> *Sheryl: And then in the middle, these telescope, so you can raise and lower the table height.*
>
> *Gary: How is that gonna work-just push, pull?*
>
> *Sheryl: I don't know about that yet.*
>
> *Gary: Well, actually, we'll let them worry about that.*
>
> *Sheryl: Really?*
>
> *Gary: Ah, have some ideas about it, but-*

The student also is asked what materials they are using. When the student asks for a suggestion the instructor instead asks "Well, what do you like? What do you think would fit in?" (4-ID-jr-LookLikeReview-Sheryl, page 6). The professor also reminds the student that transportation is an important aspect of their design, since the final client review is off campus. The instructor also gives advice on how to show off the product's functionality that the prototype cannot (4-ID-jr-LookLikeReview-Sheryl).

Case: Todd's "Look Like" Review

The student is asked about consumer feedback and how he plans on prototype the product. When the student provides the feedback the stakeholders gave him the instructor asks "as a designer, what's that tell you?" (4-ID-jr-LookLikeReview-todd, page 1). The instructor seems concerned that the student cannot visualize an issue with his axis setup; however, when another student begins arguing with todd the instructor says “He’s gotta discover that” (4-ID-jr-LookLikeReview-Todd, page 5).

When the student replies that they’re working that out he provides an alternative idea. Instructor expresses concern with student’s design, but encourages him to physically test it:

Gary: I would get a dowel rod and drill through all these and see what you think.

Todd: Okay.

Gary: And play with it. I think what’s gonna happen though is this is your, your point of axis rotating here.

Todd: It’ll move off, like that. You know what I’m saying? It’ll have this, but it can-this should still be able to rotate back.

Gary: Okay. Just-

Todd: Theoretically. Theoretically.

Gary: Okay. That’s why-that’s what, that’s what the joy of this, ah, is that.

The instructor also wants to know how the prototype is going to be built and finished. The instructor also stresses the due date as he had with the other students (4-ID-jr-LookLikeReview-Todd).

6. Mechanical Engineering Course

Through the Mechanical Engineering course, the instructor serves as a supervisor and mentor, in roles that range from inquisitive to inquisitor. The course syllabus, concept design reviews and final design review were analyzed.

6.1 *Mechanical Engineering Course Syllabus and Learning Objectives*

For the senior level mechanical engineering course, the goals and expectations of the mechanical engineering course are:

a) good design practice;
b) thorough problem definition and understanding;
c) creativity in the development of design concepts;
d) quality engineering work including analytical and physical modeling;
e) timely and well-conceived experiments and hands-on activities;
f) professional oral and written communications;
g) diligent level of effort toward well-defined milestones;
h) effective record keeping and documentation;
i) discipline in meeting personal and group obligations;
j) demonstration of teamwork with mutual respect of its members.

A panoply of expectations are listed, aligning with program objectives of most engineering programs, ABET a-k. Additional admonition is given:

> *"Because ME XXX is the capstone design course, the projects are open-ended and a thorough process is nearly as important as the solution itself. This means that your obligations and expectations will not be as clearly spelled-out as in more traditional classes."* course syllabus

And the role of the instructor is clearly delineated as the manager for the design team:

> *"In summary, treat your instructor as you would your boss in your first job. Treat your team mates as you would your colleagues in your first job*."

In a departure from the learning-centric description of the industrial design classroom, the mechanical engineering course is presented as a near version of one's first engineering job.

The syllabus for the mechanical engineering course included several notations and expectations the students should have of the instructor. A note from the instructor claims that while he or she may give good ideas or suggestions they are not ones the participants are expected to pursue. The instructor provided resources for prototyping and storage space as well. The following was a list of expectations students should have of the instructor:

- *To serve as a mentor in understanding the design process*
- *To serve as an adviser to your group in response to questions*
- *To act as a coach to stimulate the group and its members to high performance levels*
- *To insure that groups conduct their business in a professional, disciplined manner*
- *To make clear standards for performance on analyses and reporting work*
- *To give fair and timely feedback on student performance*

In addition, an admonition was given to the mechanical engineering students to mostly refrain from contacting the client directly and instead rely on the instructors as intermediaries:

> *External Contacts for Product Information and Assistance*
> *You should not contact the sponsoring company without the consent of your instructor. Inquiries will generally be organized for transmittal on a periodic basis. Contacts with product vendors or industrial organizations by telephone, FAX, or e-mail may be initiated by student groups at their own expense. Please remember that a request for information places demands on the respondent's resources without the prospect of compensation. When making such contacts, you should identify yourself as an engineering student and describe your involvement in an engineering design project at the School XXXX. Only after such an introduction has been made, and the contact has agreed to be of assistance, should you proceed to solicit information. You should thankfully acknowledge any assistance received.*

In another instance of setting expectations for professional practice, mechanical engineering students are told that a design notebook is required:

Each student is expected to maintain records of personal and group contributions in a project notebook. These records should be in a chronological order, and include meeting dates, analysis results, discussion notes, and important details which will be useful in report preparation. Your instructor will periodically ask to see your notebooks in order to evaluate your contributions.

The design notebook is a possible evaluation tool for the purview of instructor review.

The setting for the Mechanical Engineering course are rules for what one must do and cannot do. The instructor is fairly represented as an autocratic manager of the classroom.

6.2 *Concept Design Review*

The concept design reviews are a formal presentation where students show the beginning work of their project. Students are showing their concept in a presentation in front of the instructor and the other students. The instructor has students begin with formal introductions as if they are speaking to the client. During the concept design review the instructor focuses on whether the concept is complete or not and how the team has made contact with the customer. The question and answer routine is socratic with a slight confrontational tone.

Case: Robot Fish Team Concept Design Review

The Neptune's Origins group showed their concept for an aquatic robot that resembled a fish. During the presentation the instructor asks why certain parts of the concept are not completed, often repeatedly asking. The instructor also often asks for specific details and specifications on parts, materials, and design choices:

Nelson: Do you know the response time of the solenoid?

Aliyah: Can you rephrase the question?

Nelson: How fast is the angular velocity?

Aliyah: So this is supposed to have a frequently of two hertz. We've been playing with it just because that speed affects-

Questions are also brought up about specific project needs, such as waterproofing the exterior of the project. In some cases the instructor will ask if students have made important calculations and how values are derived. When the instructor sees possible issues in the design instead of pointing it out directly he continues to ask the presenters questions until the issue is realized or shown to be not an issue. When students reveal they are using a tool or material that is unique or different the instructor asks how they plan on making it, regardless if he already knows the answer. The instructor ensures students have thought out how to manufacture prototypes.

Nelson: So did I understand that right that you're gonna design your own PC- printed circuit board?

Yori: Yes.

Nelson: *And how are you gonna get that made?*

Yori: *Here at the electrical shop, maybe.*

Nelson: *Okay.*

During later parts of the presentation the instructor repeats questions he had asked earlier in the presentation. When the instructor voices a concern he maintains that it is a suggestion. He also checks if students have made fail-safe methods and whether the product is salvageable. The instructor ends with an approved budget and a "good job" (1-ME-CDR-RobotFishTeam).

Case: Cap Team Concept Design Review

The Cap Team group revealed a concept for a product that would help a staff member safely neutralize volatile chemicals. The instructor first notes that several pieces are incomplete, and at one point asks "So what are you doing at in CDR, I guess" (1-ME-CDR-CapTeam, page 2). The professor repeats this once again with another part of the model. The instructor is quick to pick up on other mistakes and errors in the team's presentation and the instructor catches what groups forget to present in the concept design review:

Nelson: *Why didn't we show those?*

Mason: *It's-*

Nelson: *It's just the spro-, or the chains, I understand.*

Jeffrey: *They're, they're, they were just hard to model.*

Mason: *And we felt without the chains the tension-*

Nelson: *It's too hard to model the tensioners?*

When the instructor asks about an issue he sees, the students reply that the orientation of the concept in the given pictures does not show that the issue does not exist. Similar to that in the Robot Fish presentation, the instructor asks how students plan to make risky design decisions work. The instructor also makes it clear that the margin of safety is an important part of the project, and that they need to "Calculate it. Don't give it to mas 'uh.' That's an addendum" (1-ME-CDR-CapTeam, page 10). Before the end the instructor asks if the customer has seen the design or the final cost, before approving the group to move onward (1-ME-CDR-CapTeam).

Case: Prop Team Concept Design Review

The Purdue Prop Pullers team proposes a portable electric tow bar for aircraft. The instructor checks to make sure the students have met basic criteria for the design. He also points out lack of symmetry in the part's functionality:

Matthew: *So then our, ah-this is how our plane steers with the handle. It, ah, can go 45 degrees, and then 90 degrees the other way. This-these are the two max conditions* *with-while towing the, the plane. And then but we recommend that you only steer the handle 35 degrees, just to ensure that you're not, um, putting too much force on the front strut.*

Nelson: Yeah, so why do we do 90 degrees one way? Why, why are we doing that?

Matthew: So we'll talk about this a little bit early-or a little bit later. But our-mechanism has a capacity without the plane to go 90 in the one direction and then 90 the other way. The one direction is for the store-away position, and the, the position on the right is so that you can, ah, insert the device underneath the-

Similar to the other groups the instructor also double-checks material choices and characteristics of those materials. In one instance the professor asks for information on the design, and then specification on the solution choice. He also makes sure the team is using the spaces open to them by asking if the shop has seen their wiring diagram. Before letting the team go the instructor asks them what the project risk is and if they are comfortable (1-ME-CDR-PropTeam).

6.3 ***Final Design Review***

The final design review is an informal presentation where the design team shows their final work in one of the labs. This review is between the team, the instructor (also known as the Project Manager), and the Project Engineer. Before beginning the instructor describes the following expectations of the final design review:

One, did you build it? One, is it fully assembled? One, is it fully assembled… Two, if it is not fully assembled per the prints, what has changed and why? All right? There's only two questions. Two, is it fully functional? If it is not fully functional, what is not working and why… which will lead you into how do you fix it, probably (2-ME-FDR-RobotFishTeam).

The instructor emphasizes that the team should answer in clearly and concisely. After this the discussions were not recorded except for the final questions.

Case: Robot Fish Team Final Design Review

Neptune's Origins began their presentation with a video demonstration of the robot working in a sink. The instructor comments on the team's video demo, often pointing out what was talked about during the CDR or outside recorded reviews. He then proceeds with questions about the product's final specifications, including battery life and product weight. Following are questions about what changed from the initial project design, and detailed reasoning behind the changes. When students reveal they used mineral oil the instructor clarifies why they used it, and then asks how they knew to do it.

Neal: Yes. It's non-conductive oil just to keep water out.

Nelson: How did you know to do it?

Joshua: *Oh, we just-*

Doug: *Yeah.*

Joshua: *It's what we used for our servo motor originally. So in the RC hobbies a lot of people fill their servo motors with mineral oil that's nonconductive.*

Nelson: *Yeah.*

Joshua: *Kind of prevents water-*

Doug: *It's probably the most useful thing I've learned, honestly.*

Before ending the grading portion of the review the professor asked what problems the students encountered. Afterwards the students were asked "to tell me [the instructor] some of the things that you actually learned in the, in the – during the course of the project" (2-ME-FDR-RobotFish-pt2, page 13). The students took this time to point out how a lot of issues arose right near the end of the project. The instructor asks about the scheduling portion of the class, and if students had feedback. The students were asked if the design was complete enough. The instructor wrapped up with a question about how the students worked together and what would they do differently? Students revealed they worked in small meetings of collaboration, and then breaking off to do their own job before coming back for a small meeting again (2-ME-FDR-RobotFish-pt2). Students reveal their odd version of team meetings:

Joshua: *Things move a lot faster when people do their thing. So short meetings together, and then people disperse, do their thing, come back, short meeting, disperse, that kind of pattern.*

Nelson: *That's interesting.*

That's different from how other teams work sometimes.

Yori: *[Laughs]*

Doug: *Really? 'Cause with us, it was just a matter of decision.*

Yori: *Yeah.*

Case: Cap Team Final Design Review

Cap Team was unable to complete their project. The instructor responds by asking repeatedly why the batteries were insufficient, and why did the team not have more batteries. The team mentions they were searching last night to which the instructor asks, "Why were we trying to get 'em last night as opposed to in the last three months?" (2-ME-FDR-CapTeam, page 2). The Cap Team FDR was not completed.

Case: Prop Team Final Design Review
Prop Team began their presentation with a formal introduction and stating what was not finished on the project. The instructor asked why the flags were not on it, to which the reply is it "was not a critical function of our [Prop Team] time" (2-ME-FDR-PropTeam_pt2, page 2). When the team reveals they implemented a relay the instructor asks why, and then later why it was not thought of in the beginning. The team is then asked to show a proof of operation, including pulling a plane. The instructor then asks a series of questions to make sure that the design constraints were met. The review is closed with good remarks (2-ME-FDR-PropTeam_pt2).

7. Discussion

When reviewing the disciplinary discourse differences between the Industrial Design course and the Mechanical Engineering course, we connect to the discussion in Klinker and Alexis (2009). Klinker and Alexis (2009) had a discussion on methods-driven and scientific approach to design education (Alexis) versus the experimental and semantic approach to design education (Klinker). In the debate Alexis and Klinker are asked to describe how their respective schools approach design education, how innovation and design are viewed, role of intuition, and other questions relative to design thinking and design making. Opinions determined from this discussion are used in comparison with trends within the industrial design and mechanical engineering courses to answer *RQ1*.

7.1 *Industrial Design Class Discourse*

For the Industrial Design students the information at the beginning of the course was relatively relaxed and open. Only absolute constraints were given, with fairly open suggestions. On the opposite end the Mechanical Engineering course gave much more instruction and expectations within the syllabus. Students were given both a set of expectations from the instructor and what to expect of the instructor. Students were also given requirements for design notebooks and dedicated meeting time outside of the scheduled course. Though, the Mechanical Engineering syllabus also showed that the professor was not meant to give all of the answers, but rather act like a boss/manager/mentor.

From the interactions in the design reviews we can determine characteristics of the instructor of and students in the Industrial Design course. As expressed earlier the instructor appears to lead the students in the beginning. He maintains a positive attitude towards any designs that students have, often referring to them as interesting or fun. A similar viewpoint appears when Kinkler describes what his school believes great design is:

> *Design should be mastered as a liberal art before it is considered a business tool. Great design comes from an artistic or cultural impulse, not from a focus group…Great design creates new culture, not just clever new utilities. Great design is about meaning first, the market second. We want the next great generation of designers who know how to experiment with form and meaning, not the next generation of strategists who churn out 8.5x11 rationalized reports on business opportunities* (Kinkler and Alexis, 2009).

Here we see that Kinkler and his institute focus on the designer's choice, not a solid business plan. During a design review the industrial design instructor explains design students have to take it to the "next level," *So as the designer, ah, National wants you to come in and-this is what I perceive that they want you-If you were the designer from one of those other kinda traditional ottomans, what would the next level be? Especially with National coming in behind the first, first group, ah, they can't be a me, too. So what's gonna attract whatever you design, a customer from buying your design versus what's already out there now. So what would be the next level? So it's color. It's form. It's dynamics. It's like you said, to me that one where you pulled the leaf down and all of a sudden, you got, you got a neat little surprise. –Glen*

The instructor describes breaking the mold, similar to what Kinkler refers to. From these two sources we can achieve an understanding that designers are meant to come up with new ideas, not necessarily the idea that already works.

7.2 *Mechanical Engineering Class Discourse*

In the Mechanical Engineering course and Alexis' point of view in Kinkler and Alexis, we achieve a different view of designerly ways of knowing, of design thinking. Instead of leading the reviews, the Mechanical Engineering instructor has teams present their project and asks questions as they come up in a responsive manner. During the concept design reviews the instructor often points out possible flaws and struggles the group may have. The professor also points out how knowing the specifications of the project are very important. In the preliminary for the final design review the instructor stresses the importance of completeness,

Nelson: One, did you build it? One, is it fully assembled? One, is it fully assembled?

Yori: Yeah.

Nelson: Two, if it is not fully assembled per the prints, what has changed and why? All right? There's only two questions. Two is it fully functional? If it is not fully functional, what is not working and why-

These characteristics of the course and its instructor help reinforce Alexis' arguments:

We also teach that good design starts with a clear point of view, but it should be based on facts, not intuition. We also talk a lot about culture, but we think design should be based on an existing culture, not create new ones. And finally, we challenge our students to experiment, but to do so like scientists (using hypotheses, building on past work), not like artists (Kinkler and Alexis, 2009).

In this engineering course an emphasis is put on having a clear point of view and using facts, not intuition. The instructor tells a group who attempts to estimate a value to "Calculate it. Don't give it to mas 'uh.' That's an addendum" (1-ME-CDR-CapTeam, page 10). At the end of the course the instructor asked students what they learned and how they grew through the course. The instructor also emphasizes how important it is to keep in contact with the client:

Nelson: *Has the customer seen the final design?*

Brody: *No, not yet. We were waiting to get it approved before we showed it.*

Nelson: *And that, and the customer hasn't seen the final cost yet.*

This lines up with Alexis's point that "we believe that design should be human centered…design should create and deliver value for its stakeholders" (Kinkler and Alexis, 2009). From the Mechanical Engineering course and Alexis's point of view we obtain a much more professional, business-oriented viewpoint of design.

7.3 *Disciplinary Discourse*

From the relations between industrial design instructors and mechanical engineering instructors we draw the following characteristics in Table 2. From the industrial design course we were able to see an emphasis on reaching the "next level" in design. The mechanical engineering coach focused on methods students learned and customer desires. In addition, the instructor also asks for detailed specifications of the design. Similarly, the instructor for the industrial design course gives design specifications to follow and becomes more serious during crunch time; however, the instructor also wants students to be passionate about their work. In the mechanical engineering course an emphasis is placed on completing project structure and function. This data helps us in answering *RQ1*.

Table 2. Characteristics of Industrial Design and
Mechanical Engineering Student-Instructor Interactions

Industrial Design	***Mechanical Engineering***
Ground-breaking / "next level" design	Design based off of methods learned and customer specifications
Provides design brief for the course	Specific statistics about design parts
Emphasizes passion for the design	Stresses the necessity to complete the project

After reviewing the characteristics of the instructors we are able to link them to previous research studies (Reich, 2009). We draw upon some of the characterizations Reich (2009) made: the supervisor, the instructor, and the mentor. These characterizations provide us with the possible roles that the instructors may fulfill (*RQ2*). The industrial design instructor shows characteristics that follow the mentor and instructor. As a mentor the instructor suggests based off of the situation of the design. As an instructor he presents functions to students and asks them to test it out themselves. The mechanical engineering instructor best displays characteristics of the supervisor and the mentor. In evidence from concept design reviews we see features of the mentor. As a supervisor the instructor ensures students have completed tasks and calculations. From what we learned we can improve upon characterizing design groups.

8. Implications for Teaching

C.P. Snow (1961) bisected the fields of humanities and sciences. Calling out the deficit in discourse between these two cultures in modern times, Snow regarded the division between the humanities and the sciences as contributing to barriers to collaborating and finding solutions to societal ills. With the computing and second technological revolution, the field and culture of engineering has widened the canyon to include another gap.

The complementary nature of *designerly* and *engineering* course content can be made explicit. What if these industrial designer students tried to solve the mechanical engineering project? Or vice versa? Can we expect our students to be ambidextrous or holistic in how they own the problem and solution? How might the mechanical engineering instructor impact the concerns of the industrial design students if switched into that context? Students and faculty alike can more mindfully chart (or help chart) a learning career balancing technical material. Such a mapping will help guide students and help faculty differentiate, highlight and synchronize their offerings. This supports students becoming innovators themselves.

The primary approaches of engineers and designers differ. For engineering students, to learn design is a hard task. They are adding Design Thinking processes to their already ensconced analytical engineering training and mental models of problem solving. Designing often requires a new approach to problem solving and, as such, the ordering of project objectives is often difficult for students to make. For example, there are switches from *opportunity push* to *needs pull*, from physical-driven to function-driven, from a goal of minimizing uncertainty to preserving ambiguity.

Many undergraduate engineering curriculums are split between learning engineering content knowledge and its application. For introductory classes in the freshman and sophomore year, engineering problem-solving is paramount and individuals toil on close-ended problems in the form of problem sets. Upper-level classes focus, in contrast, on open-ended problems and collaborating in groups, approximating practice one might find in industry. For some students, the switch is harsh, or at least, seemingly arbitrary. For others, the change is welcome. Doing problems individually differs greatly from collaborating in a team to solve some open-ended, authentic situation. Engineering education is moving towards the development of engineers who can both ask better questions and answer them more creatively.

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Biographies

Micah Lande is an Assistant Professor in the Engineering program at the Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University, USA. He holds a PhD in Mechanical Engineering, MA in Education (Learning, Design, Technology), and BS in Engineering (Product Design), all from Stanford University.

James Oplinger is a co-terminal undergraduate and graduate student in the Engineering program, with an Electrical Systems concentration, at the Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University, USA.