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Approaches to Coaching Students in Design Reviews

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Approaches for coaching students in design reviews

Abstract: Design reviews offer a unique window into understanding how design teachers help their students develop as designers. They are a prevalent practice for helping students develop design thinking expertise, although their structure and content may vary across disciplines. Understanding the teaching that occurs during design reviews can illuminate the ways teachers support students in becoming design thinkers. In this paper, we extend prior work to illustrate disciplinary perspectives of how design teachers help their students develop as design thinkers. The guiding framework is design pedagogical knowledge (PCK), the content-specific and practice-based specialized knowledge of teaching design. We analyzed five sets of longitudinal data (four individuals and one team) from an existing multi-disciplinary design review dataset (mechanical engineering, industrial design, and choreography). This paper focuses on summarizing the teaching techniques used and design thinking knowledge conveyed across these different design contexts. Results indicate: (1) design teachers across contexts share a common repertoire of design teaching techniques and design thinking process knowledge and (2) insights into what design teachers may be most concerned about regarding their students' development as designers. One contribution of this study is a language for making visible teachers' design thinking knowledge, the teaching techniques they use to convey this knowledge, and the kinds of design thinking they want to observe in their students. Teachers can use this to make sense of their own experiences and use it as a tool to discuss their experiences within a larger community of practice. Sharing results with students may help them make sense of the ways their teachers help them learn to design – both their teaching techniques and the knowledge they seek to convey.

1.0 Introduction

Design reviews or critiques are a common pedagogy for helping learners in any discipline develop and demonstrate design expertise (Dym, Agogino, Eris, Frey & Leifer, 2005; Huet, Culley, McMahon & Fortin, 2007; Goldschmidt, 2002), although their structure and content may vary across disciplines (Adams, 2016a). Many describe the practice of moving from desk to desk explaining what is right and wrong with student work as the "bread and butter" of design training (Goldschmidt, Casakin, Avidan & Ronen, 2014) and a central feature of preparing professionals as reflective practitioners (Schön, 1993).

During design reviews, students receive feedback on their design decisions and guidance in making sense of both the underlying rationales and consequences of those decisions. Coaches may notice problematic aspects of a student's work – drawing on prior experience to anticipate problems students may encounter and ways to help them work through problems, pointing out features of a design that could be wrong or improved, providing opportunities for students to learn through failure, and prodding students to reveal the thought processes that led to a current design. They may also notice promising aspects of a student's work, praising design work and particular insights or choices, and asking questions of students to help make explicit their ideas of "good design".

The how, what, and why of coaching during design reviews is considered an underdeveloped area of design research (Goldschmidt et al., 2014). Here, 'coaching' refer to the process of advice-giving in a design review, and coaches refer to the individuals participating in the advice-giving situation (e.g., teachers, experts, stakeholders, and peers). Goldschmidt et al. (2010) note that the coaching that occurs during a design review is an understudied "black box" representing a coach's personal style and accumulated wisdom. Much of the existing work is based on architecture design crits although recent work supported a global and cross-disciplinary collaboration to "analyze design reviews across disciplines" (Adams & Siddiqui, 2016).

1.1 Three aspects of design coaching - functions, contributions, and roles

Figure 1 summarizes prior work on three aspects of design coaching: functions, contributions, and roles (Adams, 2016a; Reich, Ullman, Van der Loos & Leifer, 2008). Coaching functions, contributions, and roles interact dynamically - coaches will switch among different functions and roles over the course of a design review as they seek to respond to specific student needs that call for different kinds of coaching (McDonnell, 2016; Reich, Ullman, Van der Loos & Leifer, 2008).

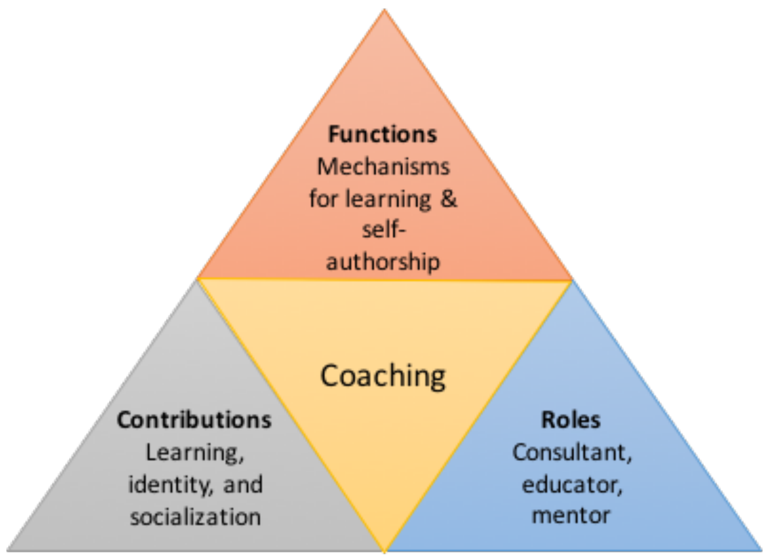

Figure 1. Three key aspects of design coaching – functions, contributions, and roles.

Functions of coaching – Mechanisms for learning and self-authorship: Key functions of coaching emphasize directing students to improve design reasoning (Ball & Christensen, 2016; Dong, Garbuio & Lovallo, 2016), offering advice in making explicit design decisions with associated rationales and consequences (Huet et al., 2007), monitoring and intervening with respect to processes and guidelines (Reich et al., 2014), and providing opportunities for students to fail, succeed, and take ownership in design decisions (Daly & Yilmaz, 2016). Coaches also help students form a design thinking mindset (Dannels, Gaffney & Martin, 2008) and navigate the non-trivial aspects of learning to use disciplinary knowledge in context (Wolmarans, 2016).

Research on strategies coaches use to affect student learning emphasize 'best practices' (Taylor, Magleby, Todd & Parkinson, 2001) and reflective practice (Schön, 1993). For example, Ledewitz (1985) identified six teaching strategies aimed at developing students' design skills such as experimenting in multiple design cycles, backward design, incremental dispensing of information, studies of solution types, experiments, and self-evaluation. Schön (1987) characterized the work of coaching as listening, telling, demonstrating, and imitating. His reflective practice framework formalizes coaching as helping students make sense of their experiences and make explicit their evolving design knowledge through reflection-in-action and reflection-on-action (Schön, 1993). This can help students critically reflect on their design beliefs in ways that support significant learning transformations (Argyris & Schön, 1974; Mezirow, 2000). For example, Goldschmidt (2006) characterizes coaching in architecture design students as moving away from a knowledge transmission model towards empowering students' self-expression and creativity, which has potential for enabling students' self-authorship as future professionals (Baxter Magolda & King, 2004).

Contributions of coaching – Learning, identity formation and socialization into professional practice. Coaches can empower students to learn how to act independently (Goldschmidt et al., 2014) and construct their own design voice as they socialize students into the complexities and ambiguities of professional practice (Brandt et al., 2013; Howard & Gray, 2014; Murphy, Ivarsson & Lymer, 2012; Oak, 2000; Oak & Lloyd, 2014; McDonnell, 2016). During design reviews, coaches also model for students their own perspectives on design practice, making visible their accumulated experience, knowledge, and belief systems – the social norms that shaped their design practice (Gray & Howard, 2016; Uluoğlu, 2000). This includes how coaches deal with routine tasks with known solutions and use practices that emphasize reductive thinking, and how they deal with new and unfamiliar tasks that emphasize adaptive thinking (Adams, Forin, Chua & Radcliffe, 2016; Ferreira, Christiaans & Almendra, 2014; Goldschmidt et al, 2016). The kinds of pedagogical talk that occurs during design reviews can reveal nuances of teaching approaches across disciplines that may not be accessible through simple reflection (Akin & Awomolo, 2016; Wolmarans, 2016), including linguistic routines and rituals inherent to a profession made visible as members of a community perform its culture (Dannels, 2005; Howard & Gray, 2014; Gray & Howard, 2016).

Roles – Consultant, educator, and mentor. Coaches fulfill a continuum of roles along dimensions of consultative, educational, and motivational functions: problem-focused interventions as either a source of knowledge or an authority figure enforcing guidelines or rules, learning-focused guidance along an educational path to impart knowledge and expertise, and mentoring-focused moral support (Reich et al., 2008). Example roles include showing the way and being a buddy offering encouragement (Goldschmidt, Hochman & Dafni, 2010; Taylor et al., 2001), inspiring students to take ownership and fostering creative tension (Marin et al., 1999), being an expert or authority (Goldschmidt, Hochman & Dafni, 2010), and modeling design acts to students (Cennamo, Brandt, Scott, Douglas, McGrath, Reimer & Vernon, 2001). Pembridge (2011) identified additional roles such as role model, career mentor, and professional socialization agent.

1.2 Variations in design reviews across disciplinary cultures and over time

Another issue to consider regarding design reviews is that the structure, content, and goals of design reviews vary across disciplinary cultures and over the course of a single project. Design reviews may take place opportunistically at a student's desk or at scheduled predetermined phases of a design process within academic settings or at project sites. Some variations that affect the practice of critiquing include the setting (individual/group, formal/informal), the types of coaches (instructors, peers, experts, and stakeholders), and interaction modalities (speech, text, drawing, gestures, and artifacts) (Oh, Ishizaki, Gross & Do, 2012).

Variations in the structure of design reviews are shaped by disciplinary cultures and ideologies. For example, architectural and product design reviews emphasize improvement (Cardella, Buzzanell, Cummings, Tolbert & Zoltowski, 2014) and direct experience with materials (Brandt, Cennamo, Douglas, Vernon, McGrath & Reimer, 2013). Variations include informal critique sessions between a teacher and student or a few students on a team, group review sessions where all students participate actively or passively in critiques of all student projects, and juried assessments where students present final work to a jury of invited professionals (Goldschmidt, Hochman & Dafni, 2010; Oh et al., 2012). In comparison, engineering design reviews are often scheduled meetings that emphasize information sharing, feedback, and obtaining approval to move on to the next step in the process (Cummings et al, 2016; Huet et al., 2007). In professional settings, design reviews emphasize engaging multiple stakeholders in evaluating a design artifact, verifying conformance to standards or values, and approving further progress (Sonalkar, Mabongunje & Leifer, 2016).

There are also disciplinary variations in terms of "best practices". In engineering, Dym et al. (2005) characterize best practices in design teaching as enabling divergent and convergent reasoning through question-asking discourse. In the context of communication, Dannels and Martin (2008) emphasize student-teacher design critique discourse as focused on judgments, process orientation, brainstorming, interpretation, recommendations, investigations, and identity invocation. According to Uluoğlu (2000), coaching in architecture studios should include demonstrating how to perform design acts and describing and interpreting design situations. In industrial design, Cennamo et al. (2011) recommend meta-discussions that target deep and potentially transformative learning. In our own work, we identified four patterns of coaching evident in mechanical engineering design, industrial design, and choreography design reviews (Adams, Forin, Chua & Radcliffe, 2016): (1) directing a student's attention to an aspect of their design and asking them to articulate their reasoning, (2) driving a design conversation to help a student make conceptual connections or see fallacies in their design thinking, (3) offering in-the-moment metacognitive perspectives on design thinking, and (4) directing a student's attention to anticipate difficulties and providing guidance for the student to make their own informed decision and develop their voice as designers.

1.3 Research purpose: Characterize approaches for coaching students during design reviews

The purpose of this exploratory project is to characterize teacher approaches for coaching students during design reviews. The aim is to make visible and shareable the ways coaches support students in becoming design thinkers. We pursued this goal with an eye towards embracing and learning from variations in design reviews by studying three different design contexts (mechanical engineering, choreography, and industrial design) across different types of design reviews (from problem formulation to solution realization). Similar to other researchers, we agree that much can be gained through exploring approaches across disciplines (Adams, 2016a). Our guiding framework draws on the idea of design pedagogical content knowledge (design PCK) as a way to make visible the accumulated wisdom that makes up effective instruction in a specific learning domain (Crismond & Adams, 2012; Mishra & Koehler, 2006).

For this study, our particular focus is on the teaching techniques coaches use in design reviews and the design thinking knowledge they convey or encourage in their students.

2.0 A framework for studying approaches for coaching design students

Pedagogical content knowledge (PCK) is a learning sciences framework that makes visible the accumulated wisdom that guides the how, what and why of teaching within a domain (Driel, Verloop & Vos, 1998; Shulman, 1987). PCK is comprised of three interconnected forms of teacher knowledge: subject matter knowledge (i.e., *what* teachers want students to know and be able to do), an understanding of how students think about or learn that subject matter (i.e., *why* teachers anticipate particular learning needs and learning progressions), and ways to effectively teach that subject matter that positively affects student learning (i.e., *how* teachers provide effective pedagogical experiences) (Ball et al, 2005).

Figure 2 summarizes our definition of design PCK for the context of design reviews (Adams, Forin, Chua & Radcliffe, 2016). The "how" and "why" aspects of design PCK are characterized by two teaching techniques: cognitive apprenticeship and teaching as improvisation. The "what" and "why" aspects of design PCK are characterized by three forms of knowledge coaches seek to convey, make apparent, or encourage in their students: conceptual knowledge (design judgment) and procedural knowledge (process management and task strategies).

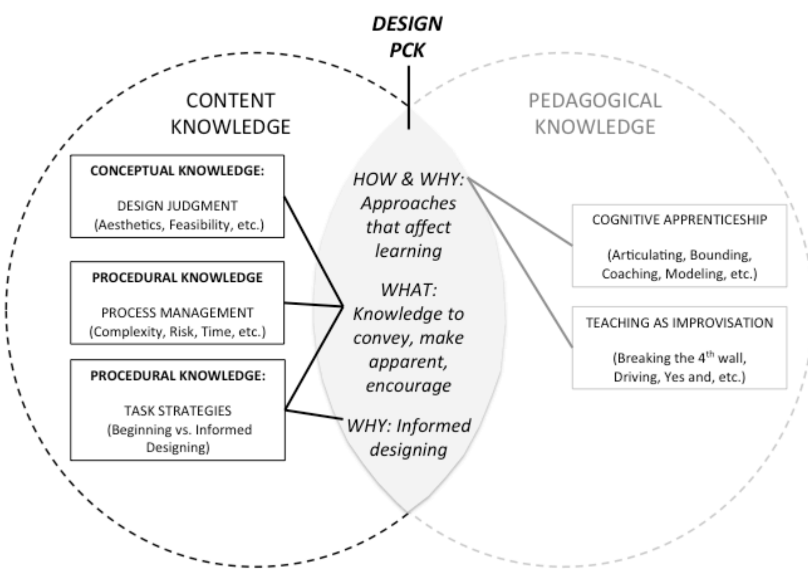

Figure 2. Frameworks for characterizing design PCK in design reviews (see Adams et al, 2016).

2.1 Approaches for coaching during design reviews – how and why

Cognitive apprenticeship and *teaching as improvisation* characterize teaching techniques coaches may use during design reviews. Both are observable research-based teaching techniques that embody social and constructivist principles of how people learn that affect student learning. The following paragraphs summarize key ideas for each framework and their relevance for coaching during design reviews.

Cognitive apprenticeship theory emphasizes how humans learn in a social manner by observing masters of a cognitive craft (i.e., coaches) in one's community of practice (i.e., a design review) (Collins, Brown & Holum, 1991). Since cognitive activity is not visible by default, teachers of intellectual subjects make their thinking visible by externalizing or bringing out "into the open" their tacit cognitive and metacognitive processes (Collins et al., 1991, p. 6). For example, in a design review a coach's actions may seem mysterious to students: what is the underlying rationale for why a coach liked or disliked an element of a student's design, or how would they go about the same task? By using cognitive apprenticeship techniques to externalize the underlying thinking behind decision-making and judgment processes, coaches can help students examine and develop their own decision-making and judgment processes as junior practitioners in the field. While cognitive apprenticeship is not often cited in design thinking research, it aligns with a tradition of design education as apprenticeship (Cross, 2006) and is synergistic with studies promoting teacher modeling of design thinking values and strategies (Goldschmidt, 2006; Oxman, 1999; Schön, 1993), scaffolding of divergent-convergent thinking combinations (Dym et al., 2005), and constructivist approaches to design teaching (Andjomshoaa, Islami & Mokhtabad-Amrei, 2011). Observable cognitive apprenticeship techniques that coaches could use during design reviews (Collins, Brown & Holum, 1991) include: articulating, coaching, modeling, scaffolding, fading, and reflecting.

The perspective of *teaching-as-improvisation* characterizes adaptive teachers as skilled improvisers (Sawyer, 2011) that draw upon existing repertoires of pedagogical patterns (Borko & Livingston, 1989; Sawyer, 2004) to respond in-the-moment to unexpected contingencies and unpredictable interactions that occur in loosely structured learning environments like design reviews. This aligns with a 'knowledge is emergent' mindset for learner-centered and constructivist approaches to facilitate learners' development of inquiry skills and individual creativity (Brennan, 2013). Teaching as improvisation is a useful design PCK perspective because it links the nature of design teaching to the nature of design activity as an iterative process (Adams, Atman & Turns, 2001) marked by opportunistic deviations (Ball & Ormerod, 1995) and co-evolutionary cycles (Dorst & Cross, 2001). As an example, Goldschmidt (2006) described the process of translating and conveying knowledge to students during design critiques as highly adaptive to the student and situation, rather than a place of teacher-directed synthesis or a consistent script. Observable teaching as improvisation techniques that coaches could use during design reviews (Beghetto, 2009; Sawyer, 2011; Vass, Littleton, Miell & Jones, 2008) include: breaking the 4th wall, denial, driving, endowing, playwriting, and "yes, and".

2.2 Approaches for coaching during design reviews – what and why

Three frameworks were used to characterize the knowledge coaches seek to convey, make apparent, or encourage in their students: *design judgment* (conceptual knowledge), *design task strategies* (procedural knowledge), and *design process management strategies* (procedural knowledge). These three frameworks define design knowledge as comprised of conceptual and procedural knowledge. Conceptual knowledge represents "knowing that" – the concepts, facts, and principles that make up a conceptual understanding of a domain of knowledge (Anderson, 1976). For the domain of design, conceptual knowledge emphasizes the principles that shape design judgment such as aesthetics and feasibility (e.g., Carvalho, Dong, & Maton, 2009) and domain-specific knowledge of precedent, materials, tools, laws, and skills (Purcell, 2003). Procedural knowledge represents "knowing how" - knowledge of how to perform or operate in a situation (Anderson, 1976). For the domain of design, procedural knowledge may be described as *task knowledge* (generally applicable techniques or heuristics for accomplishing tasks) and *process management knowledge* (general approaches for directing one's solution process such as time management) (Anderson, 1976). The informed design framework offers nine patterns of design task strategies teachers may encourage (or discourage) with students to foster effective design performance (Crismond & Adams, 2012): problem framing, doing research, idea fluency, deep modeling, balancing tradeoffs, valid experiments, focused diagnostics, iteration, and reflection.

3.0 Study design

This exploratory study seeks to identify teaching techniques coaches use during design reviews and the types of design knowledge they convey or encourage in their students. This study is situated in methods for studying pedagogical content knowledge by taking the approach of analyzing videotapes of the moment-to-moment coaching demands that occur within design reviews (Adams, Forin, Chua & Radcliffe, 2016; Ball et al, 2005). The study includes three design contexts (mechanical engineering, choreography, and industrial design) and longitudinal data covering sequences of design review phases (from problem formulation to solution realization). Data was selected from an existing shared dataset of design review conversations – digital videos with transcripts of conversations between those who gave and those who received guidance or critique during a design review (Adams, 2016b). The full dataset includes variations in review structures (e.g., one-on-one and group critiques, informal and formal reviews), phases (preliminary to final reviews), disciplinary cultures (choreography, entrepreneurship, industrial design, mechanical engineering, and service learning), design coaches (instructors, peers, external experts, and stakeholders), and student level.

3.1 Study participants

As presented in Table 1, five principles were used to select data from the larger dataset: (1) inclusive of disciplinary variation to enhance fidelity and value of study findings design review events along a continuum of aesthetic to technical perspectives, (2) longitudinal data to follow the same student or team over time (e.g., early, interim, and final reviews), (3) substantive coach-student dialogue to have sufficient data for identifying teaching approaches, (4) emphasis on undergraduate learners in their third (junior) and final year (senior) to see how coaches socialize students into design thinking, and (5) focus on instructors as coaches (as compared to peers, external experts, and stakeholders). A key rationale for including choreography in this study, besides meeting the five inclusion criteria above, is that the choreography task met criteria identifying critical invariants of design task environments (Goel & Pirolli, 1992; Daly, Adams & Bodner, 2012).

Table 1. Study participants

Discipline	Structure	Longitudinal Data	Interaction	Undergraduate Learners	Coaches
Choreography	Group sessions with coaches taking turns with references to prototypes (performances)	First, Second & Third Reviews	Learners being reviewed as individuals	Elena & Anita (Seniors in final year)	Claire, Hannah, Mia, Rachel, Sophie
Industrial Design	One-on-one sessions in shared studio space with references to prototypes, sketches, reports	First, Second & Prototype Reviews	Learners being reviewed as individuals	Todd & Sheryl (Juniors in 3rd year)	Gary
Mechanical Engineering	Formal and informal presentations with instructor questions with references to prototypes, sketches, reports	Conceptual Design & Final Design Reviews, Class Debrief	Learners being reviewed as a team	Robot Fish Team (Seniors in final year)	Nelson

Only limited information was available regarding coach expertise or knowledge; all coaches had graduate degrees and were faculty or lecturers in a discipline associated with one or more of their degrees. The mechanical engineering coach, Nelson, was a full professor in the program, and often referred to his experience as a designer in industry during design reviews. The industrial design coach, Gary, was a lecturer in the program, and during design reviews often referred to historical precedents or his own experience as a professional product designer. The five choreography coaches have substantive experience as choreographers and dancers, and during design reviews typically referenced their prior choreography projects or historical precedent.

3.2 Study contexts and participants

Choreography: a semester long choreography course with two undergraduate students (Elena and Anita) who worked independently to design a dance piece for an end-of-term public performance. Students chose the concept for their piece, selected performers, created their own movement gestures and dance composition, and were also responsible for sound, costume, and set design. There were three design reviews. Each involved performing works-in-progress followed by an informal meeting with five dance instructors who also choreographed a piece for the public performance. Reviews were conducted in a small classroom with tables and chairs arranged in a loose circle. Each instructor took a 5-7 minute turn to comment on the current performance. The students were relatively silent as they listened and wrote comments in notebooks; however, there was considerable cross-talk among the coaches. The first review focused on early concept explorations, the second on how the combination of early ideas came together as a synthesized dance work (e.g., music, set design, and costumes), and the third and final review was based on the integrated performance. This last review occurred approximately two weeks prior to the final public performance.

Industrial design: an 8-week project during a semester long industrial product design course for undergraduate students in their third (i.e., junior) year. The project was sponsored by an office furniture company looking to bring a new line of "impromptu" seating options to market. Students worked individually on their designs and met informally with the instructor (Gary) during a 6-hour studio session each week. Students could also use a fabrication laboratory to build prototypes. Most design reviews occurred in the student workspace – a busy classroom space with two back-to-back rows of tables with multiple computer displays and workspace for each student (often cluttered with sketches, foam models, and other objects). There were five design reviews: (1) a one-on-one review at the front of the room where students laid out preliminary concept sketches to discuss which five concepts should be further developed, (2) a one-on-one review a to narrow down the five concepts down to three that would be presented to the client the following week, (3) a 5-minute presentation style design review with storyboards and foam models to gather feedback from clients (two industrial designers, a product manager, and an engineer) for selecting a top design to refine for the final review, (4) a one-on-one "looks like" review of the working prototype with the instructor at student workstations to discuss how the design would be developed into a full scale prototypes for the final review, and (5) a formal presentation at the client's facility to present the final design (using a formal presentation and full-scale prototypes) and respond to questions. The clients used the final review as a basis for selecting students for a monetary award or summer internship.

Mechanical engineering design: a semester long mechanical engineering capstone design course for teams of undergraduate students in their final year. As a capstone course, the syllabus emphasized integrating various engineering sciences in an authentic, practical, and open-ended design project with real clients. Students were encouraged to treat the instructor like a boss and their teammates as colleagues. Students had a dedicated laboratory work area where they could build and test prototypes. Funding for prototypes was available with instructor approval. There were three design reviews (a preliminary design review that focused on problem definition, a conceptual design review, and a final design review) and the potential for a fourth review for teams selected to participate in an innovation award competition juried by external experts. All reviews with the exception of the final review, involved students presenting at the front of the room for about 30-40 minutes using slides projected on the wall behind them and in some cases, demonstrating physical prototypes. Their peers sat in rows of table and the instructor sat in the back with hard copies of the team's presentation and asked questions during and after the presentation. At each review the instructor granted approval for moving on to the next phase. The final design review occurred informally in the dedicated laboratory space. It began with the instructor asking the team a set of questions about the extent to which the prototype was fully assembled and fully functional, and students had about five minutes to develop a succinct response. After students presented their response, the instructor followed up with additional questions and comments, lessons learned, and told them their final grade and if they were selected to participate in the innovation award competition. Two teams (Robot Fish and Prop) were selected for the competition, and the Prop team received the award. A 14 minute debrief session conducted during the last class is also included in the dataset since the conversation focused on students' experiences with their design project.

3.3 Data analysis

Analysis involved iterative creation of codebooks (tools to consistently code the transcript data), and testing the reliability across the four members of the research team of applying codes (see Adams et al, 2016). Codebooks include code descriptions with examples that clearly represent evidence of the code so that coders can consistently apply codes to data (Lincoln & Guba, 1985) and reliably document these in Dedoose, a web-based qualitative data analysis software system (http://www.dedoose.com). The software automatically generates summaries of code applications which were used in the next section to examine descriptive summaries of codes across disciplinary contexts and chronologically over the course of a sequence of design reviews. An abbreviated version of the codebook is provided in the Appendix.

The first analysis phase began with refining pre-existing codes for *cognitive apprenticeship* and *teaching as improvisation* techniques by watching all design reviews videos together and identifying evidence of these techniques. Because neither framework has been applied to video data of design reviews, we also performed open-coding to identify any subject-matter specific instances of design teaching that fit within the general cognitive apprenticeship and teaching as improvisation theoretical frameworks. Two research team members catalogued coding examples and the research team as a whole discussed the outcomes of the open-coding process, clarified codes, and updated codebooks. For the case of cognitive apprenticeship we generated an additional code and removed an existing code. The new code of *bounding* was added to reflect the tendency of adult learners to direct their teacher or coach as to how they want to learn a topic, in contrast to young children who may be less self-directed. We deleted the concept of *fading*, since it referred to the gradual withdrawal of other support techniques rather than describing an observable and distinctive support technique itself. For the case of teaching as improvisation we deleted techniques not observed (endowing, listen and remember, and playwriting). Table 2 provides a description of observed cognitive apprentice codes and Table 3, observed teaching as improvisation codes. Examples of coded data for each set of codes are provided in the Appendix (Table A1 and Table A2).

Table 2. Cognitive apprenticeship codes (see Collins et al., 1991).

COGNITIVE APPRENTICESHIP	DESCRIPTION
ARTICULATING	Student makes their thinking visible to the coach such as explaining or justifying their performance so a coach can check their reasoning. This code may be understood as a role reversal of *coaching*.
BOUNDING	Student makes their thinking visible to the coach by directing the coach towards a subset of the problem they want guidance on. This code may be understood as a role reversal of *scaffolding*.
COACHING	Coach makes their thinking about a student's past performance visible to a student such as watching students perform and providing feedback.
MODELING	Coach makes their thinking visible to the student such as demonstrating a target skill or concept while thinking out loud about their process.
REFLECTING	Student makes their thinking visible by comparing their process to an expert's process.
SCAFFOLDING	Coach makes their thinking about a student's future performance visible to the student (helping make the students' thinking visible) such as directing the student towards a potential problem or subset of a task (a next step or future homework) or encouraging a student to finish a partially completed task.

Table 3. Teaching as improvisation codes (e.g., Sawyer, 2011)

TEACHING AS IMPROVISATION CODES	DESCRIPTION
BREAKING THE 4TH WALL	Breaking a student-teacher interaction dynamic to settle a conversation at the end of its allotted time or meta-communicating an important point such as a concept or "ground rule" that has intrinsic value for the person or field of inquiry.
DENIAL	Breaking a student-teacher interaction dynamic by rejecting what another has introduced into a dramatic frame or performance space (the opposite of the *Yes, and* code).
DRIVING	Taking over a student-teacher interaction, not letting others talk or contribute (video may need to be reviewed for corresponding physical cues such as pauses, body language, authoritative tone, etc.).
YES, AND	Affirming what another has introduced into the dramatic frame or performance space (such as accepting an assertion or revoicing and building on an assertion), allowing a dialogue of student-teacher collaboration to emerge and flow.

The second analysis phase involved cycles of generating, testing and refining codes for design knowledge coaches convey or encourage in students: *design judgment* (conceptual knowledge), *design task strategies* (procedural knowledge), and *design process management strategies* (procedural knowledge). For the cases of design judgment and design process management codes, two team members generated codes using the constant comparison method (Ryan & Bernard, 2003) with a goal of generating codes that could be inclusive across the disciplinary contexts. The constant comparison method is a way of searching for similarities and differences by making systematic comparisons across units of data. This is a process of asking, "what is this unit of data about, and how is it similar or different from others or what does it remind me of elsewhere in the broader dataset?" (Lincoln & Guba, 1985). Codes emerged through cycles of collaboratively watching the video data, identifying themes and sub-themes, reviewing and critiquing examples of themes and sub-themes, and seeking an inclusive but parsimonious set of codes. At the end of this cycle, one research team member presented the codebook to the research team for approval and any final updates.

Table 4. Design judgment conceptual knowledge codes.

DESIGN JUDGMENT CODES	DESCRIPTION
AESTHETIC	Artistic appeal (e.g., visual, auditory, and sensory), aesthetic principle (e.g., authenticity, simplicity, purity, etc.) or embodying a sense of beauty (shape, color, rhythm, texture, symmetry, contrast, organic, space, variation, juxtaposition, etc.).
COHERENCE	An integrated or cohesive system, a sense of completeness, or embodying a designer's perspective or passion.
FEASIBILITY	Feasible technical or human performance, or viable (e.g., easy to afford, easy to realize or make).
INTERACTIVITY	Practicality or experience of a design (e.g., ergonomic features, easy to use, multi-functionality or adaptability to different situations, enjoyable, etc.).
NOVELTY	Unique, evolutionary, opens up new markets or meets future needs.
(UN)PREDICTABILITY	A dramatic, unexpected, unpredictable, or counterintuitive experience (an aesthetic goal); in contrast, a sense of certainty or predictability (a feasibility goal).

Table 4 provides a description of observed *design judgment* codes. These codes complement other research (Carvalho, Dong & Marton, 2005; Christensen & Ball, 2016) including design judgment based on applying domain-specific knowledge (Wolmarans, 2016). For example, in the mechanical engineering context judging *feasibility* may involve applying physical laws, calculating maximum or minimum values, and generating sketches or simulations to model performance; in the industrial design context judging *interactivity* may involve using ergonomic rules or heuristics and drawing on precedent to imagine features that enhance usability. Examples of coded data are provided in the Appendix (Table A3).

Table 5. Task and process management procedural knowledge codes.

TASK CODES	COACH ENCOURAGES AND/OR DEMONSTRATES BEHAVIORS TO HELP A STUDENT…
PROBLEM FRAMING	Comprehend important features of the problem. May discourage or counteract behaviors such as treating design as well-defined and prematurely attempting problem-solving.
DOING RESEARCH	Learn about the problem or how the system works. May discourage or counteract behaviors such as skipping doing research and building solutions immediately.
IDEA FLUENCY	Generate and work with lots of ideas. May discourage or counteract behaviors such as working with few or just one idea, which they can get fixated or stuck on.
DEEP MODELING	Inquire into how ideas work, function, or could be made (e.g., prototyping). May discourage or counteract behaviors such as superficial drawings or models.
BALANCE TRADEOFFS	Judge options and make decisions that acknowledge both benefits and tradeoffs. May discourage or counteract behaviors such as attending only to pros or cons.
VALID EXPERIMENTS	Conduct valid experiments to substantiate design decisions. May discourage or counteract behaviors such as doing few or no tests on prototypes, or running confounded experiments that cannot provide useful information.
FOCUSED DIAGNOSTICS	Identify problematic aspects and propose ways to improve, fix, or build on them. May discourage or counteract behaviors such as unfocused and non-empirical diagnoses that cannot provide useful information for improvements.
MANAGED ITERATION	Do design in a managed way where ideas are improved iteratively through feedback. May discourage or counteract behaviors such as designing in haphazard ways or having a linear process.
REFLECTION	Reflective practice (e.g., listening to "situation's backtalk", self-monitoring behavior, assessing the value or relevancy of design strategies). May discourage or counteract behaviors such as tacit designing with little self-monitoring or not being open or willing to reflecting on past.
PROCESS MANAGEMENT CODES	COACH ENCOURAGES AND/OR DEMONSTRATES BEHAVIORS TO HELP A STUDENT…
COMPLEXITY MANAGEMENT	Manage complexity such as revisiting or negotiating scope of work, and assessing feasibility within a timeline.
RISK MANAGEMENT	Anticipate and attend to risks associated with planning, communicating, or developing a design.
TIME MANAGEMENT	Manage time to successfully complete tasks within a prescribed timeframe.
MULTIPLE PERSPECTIVES	Manage plurality of perspectives to develop own perspective and having a tolerance and appreciation for ambiguity.
SUGGEST DON'T TELL	Exercise and have agency in design judgment under ambiguous circumstances.

Table 5 provides a description of observed *design task strategy* and *design process management strategy* codes (examples of coded data are provided in the Appendix in Table A4). Similar to design judgment codes, design process management strategy codes were generated from the data using the constant comparison method (Ryan & Bernard, 2003) and represent strategies for directing an overall solution approach such as managing time, risk, and project complexity. For the case of design task strategies, a pre-existing framework of informed designing was used as codes. This framework characterizes nine design task behaviors that coaches might encourage to foster 'informed designing' as a performance goal or behaviors they might discourage that are indicative of what beginning designers do (Crismond & Adams, 2012). As an example, for the design task strategy of "balance tradeoffs" beginning designers are prone to ignore complexity and trade-offs and make design decisions without weighing all options or attending only to pros of favored ideas or cons of lesser approaches. In a design review, coaches may encourage or demonstrate behaviors such as using words and graphics to compare pros and cons, and making selections that take into account multiple criteria. As another example, for "managed iteration" coaches may encourage students to design in a managed way where ideas are improved upon iteratively through feedback, or discourage or counteract behaviors such as designing in haphazard ways or having a linear non-iterative process.

After resolving all codebook issues, the team coded all transcript data to consensus. As an example, two research team members applied the cognitive apprenticeship and teaching as improvisation codes, compared codes, and agreed upon a final code. All coding decisions were recorded in Dedoose. Code applications were allowed to co-occur to catalogue interactions between the how, what, and why elements of design coaching as illustrated in Figure 2. In other words, an excerpt of transcript data might have evidence of multiple codes – such as *scaffolding*, *focused diagnostics*, and *risk management* – and these co-occurrences allow identifying not only the teaching approaches used but also the content of the coaching (what conceptual and procedural knowledge coaches sought to demonstrate or encourage in students). To illustrate, consider the following simple example of Rachel, a choreography coach, describing her reaction to an element of Elena's choreography:

> Rachel: "I'm enjoying watching your dancers…I really liked your cast, like the way they are all together…a lot of these gestures that sort of have something to do with like the head or like things coming out of the head or like I'm really enjoying those."

Here, Rachel is providing feedback to Elena – she is *coaching* her about particular aspects of her choreography, praising the *coherence* of the piece (how the cast is "all together") and the *aesthetics* of a particular gesture involving "things coming out of the head". In Dedoose, this passage would be coded as the cognitive apprenticeship technique of *coaching,* referencing design judgement codes of *coherence* and *aesthetics*.

4.0 Results

Results are presented to support comparisons across contexts and over time. This enables assessing the fidelity of observations (e.g., are teach approaches relevant across variations) and identifying patterns of interesting similarities and differences.

4.1 Patterns in teaching techniques coaches used during design reviews

Cognitive apprenticeship - Shared repertoire: As shown in Figure 2, all cognitive apprenticeship techniques were observed across contexts with one exception. There were no observations of students comparing their design processes to an expert's process (the code of *reflecting*). Research on the same dataset indicates coaches often worked to help students reflect on their own reasoning (see Adams et al, 2016); however, this was typically guided by the coach as compared to the student directing their own reflective practice.

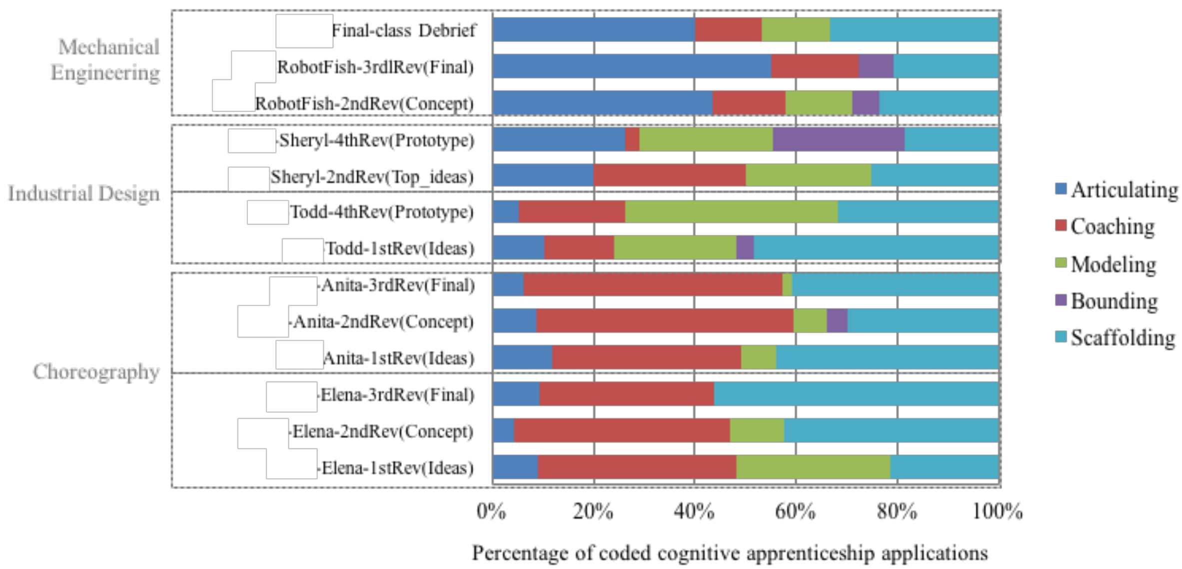

Figure 2. Observations of cognitive apprenticeship techniques across design contexts and phases as percent of total number of observations.

Across disciplinary contexts, there was a common emphasis on the use of *scaffolding* (i.e., coaches directing students towards a potential problem or breaking down a complex task into smaller sub-tasks). In most design reviews *scaffolding* accounted for more than 20% of observed cognitive apprenticeship techniques. Among the remaining techniques, there were notable variations across contexts. In mechanical engineering *articulating* (i.e., students making their thinking visible to a coach so a coach can check their reasoning) and *scaffolding* were predominant and this was relatively consistent across design reviews. As a reminder, the structure of these design reviews emphasizes students presenting their work with the coach asking questions of the team as needed. In industrial design *modeling* (i.e., a coach making their thinking visible to students such as demonstrating a skill or thinking out loud about their reasoning) and *scaffolding* were predominant; in choreography, *coaching* (i.e., a coach watching students perform and providing feedback) and *scaffolding* were predominant.

Cognitive apprenticeship - Variations: Some of the observed disciplinary differences may be attributed to the structure of the design reviews – structures that also shaped the ratio and percentage of who was talking and when. This may be an indicator of disciplinary values about what students should know and be able to do. When students were the predominant speakers in a design review the techniques of *bounding* and *articulating* were broadly evident, and when coaches were the predominant speakers the techniques of *scaffolding*, *coaching*, and *modeling* were more evident. For example, the turn-taking structure of the choreography reviews was a consistent multi-perspective informal review process where five different instructors provided feedback - making *coaching* a likely occurrence as well as *modeling* (making visible multiple perspectives on principles of choreography design). The structure of the mechanical engineering reviews was teams, not individuals, and emphasized formal presentations at the front of the classroom or informal demonstrations in the laboratory. As such, students were more likely to be talking during the reviews (i.e., *articulating*), with the coach entering the dialogue using *coaching*, *modeling*, and *scaffolding* techniques to probe student's reasoning. For the final debrief these roles were switched with the coach *scaffolding* students in *articulating* their reasoning for why they were or weren't meeting their schedule and *modeling* his professional wisdom regarding time management and professional success (see also Adams et al, 2016).

In comparison, the structure of the industrial design reviews in this study was consistently an informal one-on-one process in the student work area, offering the coach considerable flexibility with responding to the perceived needs of each student. While Gary's repertoire of cognitive apprenticeship techniques was similar to the other teachers in this study, Gary's approach to supporting Sheryl and Todd was quite different. For example, in the "looks like" review where students discussed their approach for developing a prototype for use at the final design review, Gary used *articulating* and *modeling* techniques with Sheryl as compared to *scaffolding, coaching* and *modeling* techniques with Todd. In this review, Sheryl had worked through many elements of her design and multiple times directed Gary towards targeted information she needed (i.e., *bounding*) and Gary *modeled* his professional know-how. In contrast, Todd was struggling with the feasibility of his concept, and Gary engaged in a variety of techniques to help Todd see and work through the fallacies of his approach (i.e., *articulating, coaching, modeling,* and *scaffolding).*

While this is only an exploratory sample, some of these patterns appear to be associated with the changing goals of design reviews over time. For the choreography reviews, the pattern is relatively similar over time with some decrease in *modeling* (i.e., a coach demonstrating their knowledge or talking out loud about their reasoning) as the students approach the final design review. This may indicate that by the final design review the goal is to ensure that students are able to deliver their final performance. For the mechanical engineering reviews, there appears to be an increase in *articulating* over time perhaps because students are explaining in considerable depth how their design works or achieves requirements, and an associated decrease in *coaching* and *scaffolding* to signal a coach moving away from helping students diagnose and troubleshoot their work. Perhaps due to the flexibility afforded by the industrial design one-on-one reviews it was difficult to discern any notable patterns.

<u>Teaching as improvisation - Shared repertoire</u>: As shown in Figure 3, all teaching as improvisation techniques were observed across contexts with the exception that coach *driving* (i.e., a coach taking over an interaction and not letting others talk or contribute) was not observed in the choreography reviews. It is important to note that the turn-taking structure of the

choreography reviews could be interpreted as *driving*, a structure in which the instructors controlled the student-coach dynamic. For both industrial design and mechanical engineering, *driving* was associated with supporting concept development and troubleshooting. Similarly, *denial* (i.e., breaking an interaction by rejecting what another was introduced) was evident in all contexts but was most likely to be observed during design reviews where concepts had reached a level of development where they could be productively critiqued or challenged. It is important to note that driving and denial are techniques that many discourage because they break a teaching as improvisation frame (Sawyer, 2011); however, in the context of design reviews where there are many possible solutions it may be that under certain conditions these are necessary and useful interruptions.

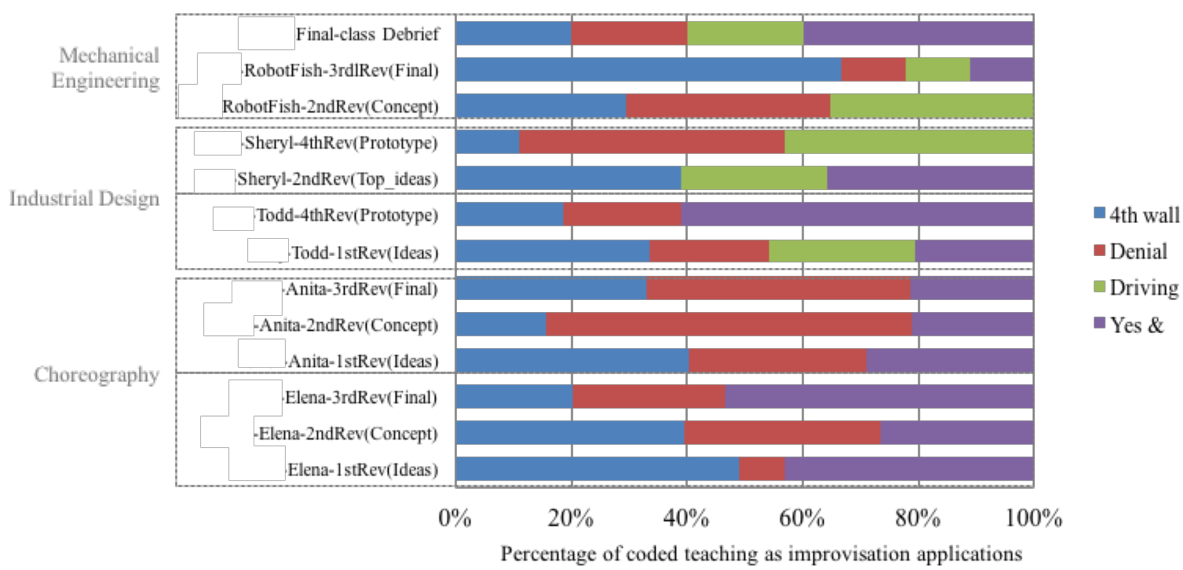

Figure 3. Observations of teaching as improvisation techniques across design contexts and phases as percent of total number of observations.

All coaches extensively used *breaking the 4th wall* techniques (i.e., breaking a coach-student interaction to meta-communicate an important point that has intrinsic value for the person or domain of inquiry). This indicates that teachers create opportunities for meta-teaching moments, often in-the-moment during any design review, as needed (see Adams et al 2016). Examples include a debrief on time management in the mechanical engineering context, guidance on reflective practice in the choreography context, and sharing strategies for managing risk in the industrial design context.

Teaching as improvisation – Variations: There was considerable use of *"Yes, and"* techniques (i.e., affirming or accepting what another has introduced into an interaction and building off that assertion) in choreography and industrial design reviews as compared to mechanical engineering reviews. Both the choreography and industrial design reviews were informal in ways that suggest these structures fostered a *"Yes, and"* interaction dynamic. For the case of choreography, the interaction was among the five coaches who could build on each other's feedback; for the case of industrial design, the interaction was one-on-one with the student and the instructor building on each other's assertions. As a comparison, *"Yes, and"* techniques represented 40% of the teaching as improvisation techniques observed in the final debrief for mechanical engineering. This debrief was markedly different in structure from the formality of the concept and final design reviews. It was described as a Socratic dialogue where the coach pushed students to reason through their time management challenges and built on ideas shared to pull out features of being a professional engineer (see Lande & Opplinger, 2014; Adams et al, 2016). With the exception of the final debrief in mechanical engineering, *breaking the 4^th^ wall* techniques typically decreased as students progressed to later design review stages.

4.2 Patterns of what knowledge coaches conveyed or encouraged in their students

Design judgment – Shared repertoire: As shown in Figure 4, instructors referenced all conceptual knowledge design judgment codes during the design reviews - with the exception that the mechanical engineering teacher did not emphasize *novelty* (i.e., being unique, evolutionary, opening up new markets). There were also notable differences across contexts. The choreography teachers strongly emphasized *aesthetics* (i.e., having an artistic appeal, following an aesthetic principle such as simplicity or purity, or embodying a sense of beauty through form, color, texture, and juxtaposition) and *coherence* (i.e., embodying a holistic essence or integrated system cohesiveness including how the idea of a design aligns with a designer's passion). The industrial design teacher emphasized *aesthetics*, *interactivity*, and *novelty* early in the process, and strongly emphasized *feasibility* and *aesthetics* later in the process. The mechanical engineering teacher primarily emphasized *feasibility,* but also referenced other issues.

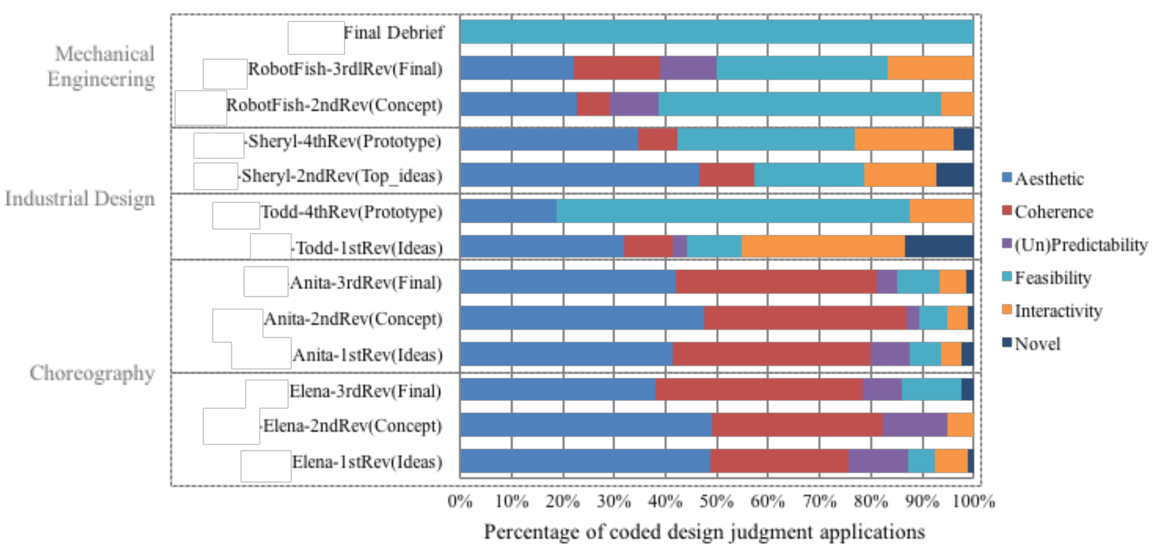

Figure 4. Observations of design judgment conceptual knowledge codes across design contexts and phases as a percent of total number of observations.

Design judgment – Variations: There were also disciplinary differences in the application of design judgment codes. For example, in the choreography and industrial design contexts, students were encouraged to integrate *unpredictability* (i.e., a dramatic, unexpected, or counterintuitive experience) into their designs to create drama or surprise. In the mechanical engineering context, the instructor encouraged solutions that would be *predictable* (i.e., providing a sense of certainty) as way to establish the reliability of a solution. Also, in the mechanical engineering context *coherence* referred to linking system complexities and producing a complete or integrated solution; for choreography and industrial design, *coherence* referred to the aesthetic and material integration of form and function. This seems to indicate that in more aesthetically-centered domains *coherence* speaks to integrating form and function as an experience, whereas in more technically-centered domains *coherence* speaks to integrating system performance. There were also unexpected commonalities: the choreography teachers used *feasibility* to articulate concerns about the limitations of the human body or human movements, and the mechanical engineering teacher addressed *aesthetics* to encourage students to make the robot fish look authentic.

Design task strategies – Shared repertoire: All design task strategy codes were also evident across contexts - with the exception that the choreography teachers did not encourage *doing research* (i.e., building knowledge about the problem or how the system works) and the mechanical engineering teacher did not emphasize *problem framing* (i.e., delaying picking a solution to comprehend important features of the problem). It should be noted that we did not have access to the first, or preliminary, mechanical engineering review where problem framing might be a likely focus. Similarly, doing research may take on a different meaning in choreography where the students and instructors often referenced historical precedents such as particular dance companies, gestures, and aesthetics (classic, modern, critical).

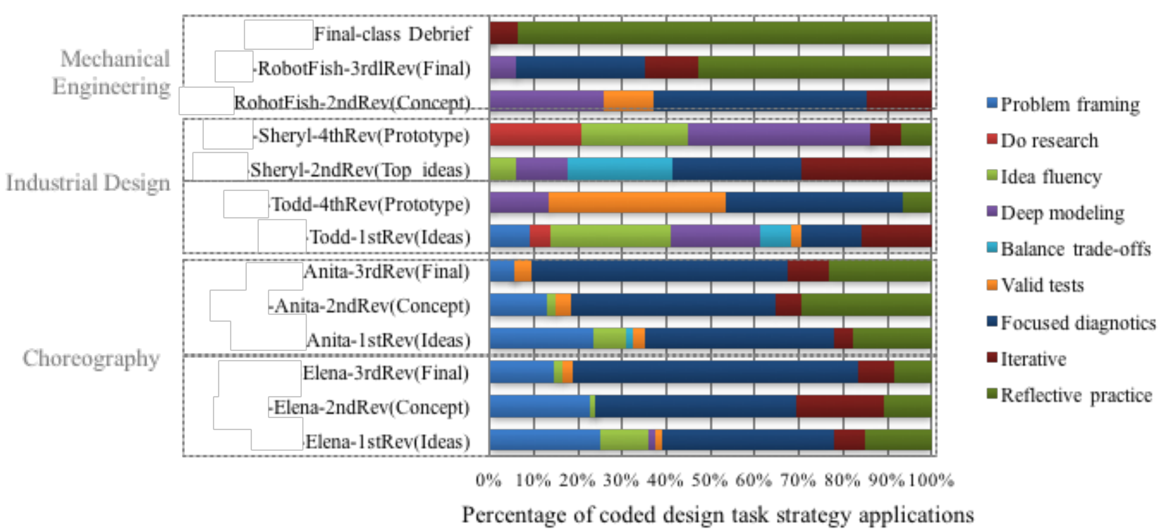

Figure 6. Observations of design task strategy codes (procedural knowledge) across design contexts and phases as a percent of total number of observations.

Across all contexts and review phases, all instructors strongly conveyed and encouraged *focused diagnostics*, and either opportunistically or intentionally encouraged students to *reflect*. *Focused diagnostics* involved troubleshooting solutions – identifying problematic aspects and proposing ways to improve them as well as bringing problem framings and solutions into greater alignment; *reflecting* involved self-monitoring practices to assess the current situation and the quality of design decision making (see Table 5). While at first glance *focused diagnostics* appears to focus on the performance of solutions, one of the troubleshooting lenses coaches used was the extent to which a current solution was *coherent* or aligned with the essence or original problem framing. In this way, aspects of *problem framing* were concurrent with *focused diagnostics*, and in some cases this was associated with encouraging design iterations.

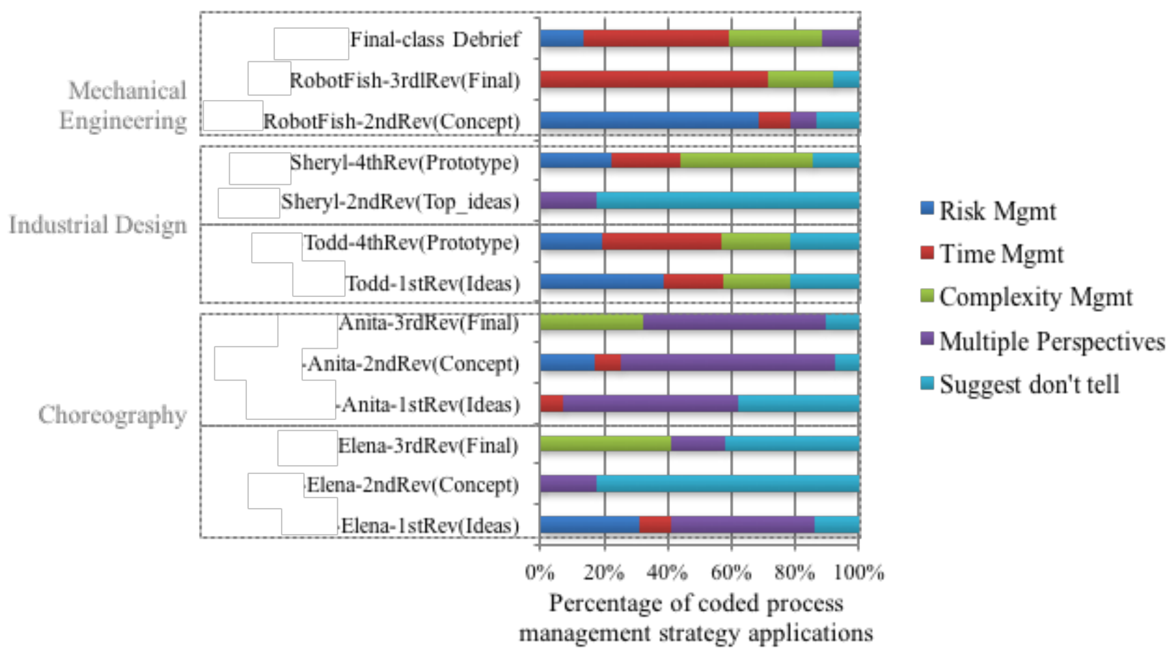

Figure 7. Observations of design process management strategy codes (procedural knowledge) across design contexts and phases as a percent of total number of observations.

<u>Design task strategies – Variations:</u> Comparing across contexts, the choreography instructors emphasized *problem framing*, *iteration* and *reflection*. Along with *focused diagnostics*, these strategies were emphasized relatively consistently across the different design reviews although the early emphasis on *problem framing* decreased over time. In comparison, there was no clear pattern of task strategy codes observed with the industrial design instructor. Similar to previous insights, the instructor appeared to draw on strategies differently with each student. As a reminder, one explanation for this was the benefit of a one-on-one design review structure that may afford student-centered flexibility to draw on his working repertoire to adapt in-the-moment to individual student needs. While there was no definitive pattern, the industrial design

instructor emphasized *iteration* (i.e., doing design in a managed way where ideas are improved iteratively through feedback) earlier in the design review progression rather than later. This may indicate that iteration was associated with problem framing as compared to optimizing a solution. This instructor was also more likely to encourage *idea fluency* (i.e., generating and working with lots of ideas) than the other instructors. The mechanical engineering instructor emphasized *deep modeling* (i.e., making models or sketches that support inquiry into how an idea works, functions or could be made) and *conducting valid tests* to substantiate design decisions earlier in the design review progression. There was also an increased emphasis on *reflective practice* in the final review and debrief.

<u>Process management strategies – Repertoires and variations:</u> All procedural knowledge process management strategy codes were evident in each context, and *suggest don't tell* (i.e., encouraging students to take agency in their design judgment under ambiguous circumstances) was evident in every design review with the exception of the mechanical engineering final debrief. Unlike the other contexts, *multiple perspectives* (i.e., managing a plurality of perspectives) played a central role in the choreography design reviews, in part because of the multiple coaches and the ways they complemented and conflicted in the feedback they provided. As compared to the choreography instructors, the industrial design and mechanical engineering instructors were more likely to emphasize *risk* (i.e., anticipating and attending to risk), *time* (i.e., managing time successfully to meet commitments), and *complexity management* (i.e., revisiting and negotiating scope of work, assessing feasibility within a timeline) strategies. In particular, *time management* played a central part in the mechanical engineering debrief with the whole class.

4.3 Patterns of co-occurrence linking teaching techniques and design knowledge

Table 6 provides the output of the co-occurrence analysis provided by the Dedoose software. The top row represents observed cognitive apprenticeship and teaching as improvisation techniques. The column to the far left represents the kinds of conceptual and procedural design knowledge demonstrated and modeled by coaches and/or encouraged in students - design judgment, design task strategies, and design process management strategies. Each cell represents the number of times a teaching technique co-occurred with a form of design knowledge – offering insights into the kinds of teaching techniques used and for what teaching purpose. Cells shaded in grey signify the most prevalent combinations and is calculated by the Dedoose software.

While this analysis does not allow explanatory statements, it does indicate that instructors in this study *as a group*:

- Used *breaking the 4th wall* frequently to create teaching moments about the meaning of particular design values (*aesthetics, coherence*, and *feasibility*) and design strategies (*problem framing, focused diagnostics, iteration*, and *reflective practice*).
- *Modeled* for students their experience-based knowledge of *aesthetics, feasibility, risk, time*, and *complexity*.
- Used *coaching* techniques to give students feedback on *aesthetics, coherence, focused diagnostics*, and ways to deal with *plurality*

- Pushed back or *denied* the ways students were considering *aesthetics, coherence*, and *focused diagnostic* troubleshooting.
- Used *scaffolding* techniques to break down into more cognitively manageable subtasks issues regarding *aesthetics, coherence, feasibility, focused diag*nostics, and *time*.

Table 6. Co-occurrences between design knowledge and teaching technique codes.

		COGNITIVE APPRENTICESHIP					TEACHING AS IMPROVISATION			
		ARTICULATE	BOUND	COACH	MODEL	SCAFFOLD	BREAK 4TH WALL	DENIAL	DRIVING	YES AND
JUDGMENT	AESTHETIC	24	12	192	56	199	70	24	42	84
	COHERENCE	18	14	156	26	186	50	23	25	50
	(UN) PREDICTABILITY	8		53	11	43	10	4	1	15
	FEASIBILITY	24	3	34	46	70	46	12	26	25
	INTERACTIVITY	11	7	31	24	25	23	2	32	13
	NOVEL	0	0	11	11	9	7	1	17	8
TASK STRATEGY	PROBLEM FRAMING	15	1	52	18	62	36	4	11	29
	DO RESEARCH	1	1		10		1	1	22	
	IDEA FLUENCY	8	3	7	26	15	17	1	10	13
	DEEP MODELING	10	2	3	19	41	21	3	38	9
	BALANCE TRADEOFFS	6		3	9	4	8		10	2
	VALID TEST	2		2	11	22	17	3	3	6
	FOCUSED DIAGNOSTIC	28	11	257	59	262	61	39	24	90
	ITERATIVE	12	3	50	17	80	44	12	24	23
	REFLECTIVE PRACTICE	33	22	55	4	54	37	8	1	20
MANAGEMENT STRATEGY	RISK MGMT	2	8	4	39	12	36	8	21	
	TIME MGMT	20		7	28	41	39	6	24	1
	COMPLEX. MGMT	6	10	11	35	20	18		43	2
	PLURALITY	3	3	36	2	28	9	3		18
	SUGGEST DON'T TELL	2	10	23	65	51	53	7	53	23

Note: Shaded cells denote a relative high frequency across all possible co-occurrences. This is a value calculated by the Dedoose software.

These patterns suggest that coaches were most worried about or found most promising in student work issues related to *coherence*, *feasibility*, and *aesthetics*; *focused diagnostics*, *iteration*, and *reflection*; *time, risk,* and *complexity management*.

5.0 Discussion

In this exploratory study, we found that instructors in choreography, industrial design and mechanical engineering share a repertoire of (1) cognitive apprenticeship and teaching as improvisation techniques for teaching students to design, (2) design thinking knowledge for judging design decisions, and (3) design thinking knowledge as task and process management strategies. Collectively, these codes offer a language for design teachers to share their teaching practices with others and be explicit about their teaching in ways that enhance their performance as educators.

We also found interesting variations across disciplinary contexts, design review phases, and design review structures. A summary of observed cognitive apprenticeship and teaching as improvisation techniques observed in this dataset is provided in Table 6. A summary of observed conceptual and procedural design knowledge conveyed by instructors or encouraged in students in this dataset is provided in Table 7.

Table 6. Shared teaching practices and variations (disciplinary, design reviews, review structures)

	Shared practices	Disciplinary variations	Design review sequence variations	Design review structure variations
Cognitive apprenticeship techniques	All techniques observed, with exception of *reflecting* Prominence of *scaffolding* (at least 20% of applications)	Choreography: prominence of *coaching* and *scaffolding*	Choreography: relatively consistent across students over time, some decrease in *modeling*	Choreography: turn-taking structure for all design reviews may contribute to consistency of techniques across reviews
		Industrial: prominence of *modeling* and *scaffolding*	Industrial: unable to discern patterns across students	Industrial: one-on-one structure for both design reviews, but appears to be variations in techniques across students based on student needs
		Mechanical: prominence of *articulating* and *scaffolding*	Mechanical: some increase in *articulating* as approach final design review, increase in *scaffolding* in final debrief	Mechanical: presentation style format for design reviews (one formal, one informal) emphasize *articulating* and *scaffolding* (also for final debrief)
Teaching as improvisation techniques	All techniques observed with exception of *driving* in choreography Prominence of *breaking the* 4^{th} *wall* (20% or more of applications)	Choreography: no *driving*, prominence of *breaking the* 4^{th} wall and *"Yes and"*	Choreography: decrease in occurrence of *breaking the* 4^{th} wall from first to second review	Choreography: turn-taking structure as implicit coach *driving*
		Industrial: prominence of *breaking the* 4^{th} wall and *"Yes and"*	Industrial: decrease in occurrence of *breaking the* 4^{th} wall *Driving* associated with concept development and troubleshooting	Industrial: flexibility of one-on-one structure may support more teaching as improvisation techniques
		Mechanical: low occurrence of *"Yes and"*	Mechanical: d*riving and denial* associated with concept development and troubleshooting	Mechanical: Socratic dialogue of final debrief associated with high occurrence of *"Yes, and"*

Table 7. Shared knowledge practices and variations (disciplinary and design review goals).

	VARIATIONS
DESIGN JUDGMENT	Choreography • Emphasis on *aesthetics* and *coherence* • *Unpredictability* valued as disrupting the status quo or having aesthetic appeal • Design judgment emphases relatively consistent over design review progressions Industrial • Emphasis on *aesthetics*, *interactivity*, and *novelty* • In later design reviews, encouraging *feasibility* increases in use and *aesthetics* decreases in use Mechanical: • Emphasis on *feasibility* and *aesthetics* (may be due to this particular project) • In later design reviews, encouraging *coherence* increases in use (may be an indicator of moving from part to whole system performance)
PROCESS TASK STRATEGIES	Choreography • Emphasis on *focused diagnostics, problem framing, iteration, reflection* • Encouraging *problem framing* decreases over design review progression • No evidence of *doing research* Industrial • No clear pattern, but emphasis on *focused diagnostics; m*ore likely to encourage *idea fluency* • Encouraging *iteration* decreases over design review progression Mechanical • Emphasis on *focused diagnostics, as well as deep modeling* and *conducting valid tests* • Encouraging *deep modeling* and *conducting valid tests* decreases over design review progression; *Reflection* increases over design review progression • No evidence of *problem framing*
PROCESS MANAGEMENT STRATEGIES	Choreography • Emphasis on *suggest don't tell*; unique encouragement of *plurality* Industrial • Emphasis on *risk, time, complexity management* Mechanical • Emphasis on *risk, time, complexity management*

This exploratory study also provided insights into what these disciplinary instructors may be most concerned about regarding their students' development as designers. This was demonstrated through an observed emphasis on: (1) meeting performance goals of *aesthetics*, *feasibility*, and *coherence*; (2) performing *focused diagnostics*, *iteration*, and *reflection*; and (3) managing *time, risk,* and *complexity*. Teachers' extensive use of *focused diagnostics* strategies suggests they perceive students need considerable guidance with diagnosing their own designs and that diagnosing solutions provides an entry point for iterating and reflecting on solution-problem alignments.

6.0 Implications and future work

Implications for theory: The benefits of situating this exploratory study in the pedagogical content knowledge (PCK) framework is that it offers tools for making visible the rich and complex elements that make up design coaching in design reviews (Mishra & Koehler, 2006). The *cognitive apprenticeship* and *teaching as improvisation* lenses made visible the "how and the why" of how teachers approach coaching in design reviews in terms of constructivist learning theory that is readily observable and shareable as design coaching techniques across contexts. The *design judgment* and *design task and management strategy* lenses made visible the "what and why" of the design knowledge coaches seek to demonstrate, convey, and encourage in their students.

While the use of the PCK framework has a rich history in K-12 science education and teacher professional development (Grossman, 1990), it is a relative newcomer in design education. As a recent example, Hynes (2012) investigated design teaching in middle school and found that teachers use prototypes and iteration as a form of design PCK to help students clarify or identify new needs or imagine future versions. Phillips et al. (2009) used the PCK construct to create a subject matter taxonomy that could serve as a content guide for industrial design education. While relatively new to design education, this study indicates how the PCK framework can offer substantial value for teacher professional development. It offers specific tools for understanding the design-specific practices coaches use to help students learn to design and provides a first step towards unpacking the relationship between what coaches do and their design-specific knowledge about their students (where they struggle, where and how they need guidance, and what kinds of naïve conceptions coaches need to help students overcome). We see the coding schemes summarized in the Appendix as observable practices and a first step towards creating a guide for noticing and reflecting upon ways to enhance student learning in relation to learning goals and ways to enhance curriculum that can integrate the complex web of elements that make up effective instruction (Crismond & Adams, 2012).

By taking a variation approach, we identified similarities and differences of the kinds of coaching that occurs during design reviews across disciplinary contexts, different review structures, and design students. We observed considerable similarities, indicating how design coaches in very different contexts using quite different review structures share a common repertoire as a common meeting place for discussing design teaching and learning through shared experiences. Study results also suggest that design teaching may be a form of situated knowledge: teachers in this study, although they varied in disciplinary perspectives, flexibly drew from a common repertoire of teaching techniques to *adapt to the situation at hand*, whether it was student-specific or specific to the focus of a particular design review (e.g., problem formulation, conceptual design, etc.).

Implications for practice: The coding schemes provide a language for making visible teachers' design thinking knowledge, the teaching techniques they use to convey this knowledge, and the kinds of design thinking knowledge they emphasize with their students. Being able to make explicit and shareable the ways design teachers coach their students to design is an area of considerable value – filling a much-needed gap in design education. This provides a language to help design teachers across disciplines make sense of their own experiences as a form of reflective practice and discuss their experiences within a larger community of practice. Sharing results with students provides opportunities to help them develop an awareness of design thinking (beyond a method to follow) and make sense of the ways their teachers help them learn to design and strengthen their design processes and products.

Limitations and future work: This is an exploratory study that used purposeful sampling to explore the validity and fidelity of a set of coding schemes situated in the PCK framework. Rather than assess inter-rater reliability our focus was on building consistent common ground for describing the work of coaching during design reviews. As such, study results are not meant to be generalizable; rather, the emphasis was to use variations to create a broad space for understanding approaches to coaching during design reviews that leverages the value of multiple perspectives. Overall, this study indicates the benefits of the PCK framework and coding schemes for continuing additional analysis, in particular applying the frameworks to other data in the shared DTRS 10 dataset. The extent to which practices were both shared and distinctive of context indicates the fidelity of the design PCK framework developed and its potential for additional study – particularly across disciplines. This study was also not designed to offer explanatory accounts. Future work should focus on other methods that fully support eliciting teacher knowledge (perhaps in combination with observing teachers in action) as well as making the link between what students perceive as the strengths and weaknesses of their design work and how this relates to the feedback, coaching, and guidance they receive from coaches.

7.0 Acknowledgements

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Appendix

Table A1. Cognitive apprenticeship codes with examples.

COGNITIVE APPRENTICESHIP CODES	EXAMPLES
ARTICULATING: Student makes their thinking visible to the coach such as explaining or justifying their performance so a coach can check their reasoning. This code may be understood as a role reversal of *coaching*.	After being asked, Anita explains the title of her piece, "Purlicue": *I mean for me, this idea that first of all there is a definition for this word and to me this was very gestural and articulate, like looking at the distance, you know, because you have to be very precise and measuring that, and that has something to do with the hands, and the hands are something that I'm working with. And I'm looking at the word purlicue and the way you write it and the way the letters are formed and the way you say it on your tongue is very – you know, it has that rounded flowy-ness…*
BOUNDING: Student makes their thinking visible to the coach by directing the coach towards a subset of the problem they want guidance on.	Anita asks a question to the coaches during her second review: *Can I ask a general question about, for you, notice or feel anything about the tempo of the piece, that like maybe…it's lagging or it's just like for me, when I keep watching it I feel like it's…But I don't know how fresh eyes see it.*
COACHING: Coach makes their thinking about a student's <u>past</u> performance visible to a student such as watching students perform and providing feedback.	Hannah responds to Elena's first performance and offers feedback: *Um, the line with the gestures and the breath feels like something is just not developed yet to me. So I was like 'oh, that has potential to go somewhere.' I didn't get a lot from it yet, but…I could see it was heading in an interesting direction. Um, the trio line felt a little too frontal to me, like I wanted it to build in three-dimensional quality at that point…*
MODELING: Coach makes their thinking visible to the student such as demonstrating a target skill or concept while thinking out loud about their process.	Gary models his approach during Sheryl's Prototype Review: *...what I would do is I would maybe simulate that, and maybe get online and look at outdoor furniture pieces or whatever they have for posts and attachments, because it's gotta be attached, because when you put your section down you can't have anything sticking down. It would be easy…Now I wouldn't spend a lot of time on that. Keep it nice and clean because that's a detail that'll work out, and if you want to keep it, this is wonderful it's so nice and clean.*
REFLECTING: Student makes their thinking visible by comparing their process to an expert's process.	Not observed in the selected data set
SCAFFOLDING: Coach makes their thinking about a student's <u>future</u> performance visible to the student (helping make the students' thinking visible) such as directing the student towards a potential problem or subset of a task (a next step or future homework) or encouraging a student to finish a partially completed task.	Nelson directs the Robot Team to an aspect of their design: *Hold on just a second. I wanna ask – I wanna go back just second. What prevents the fish from taking a nose-down attitude when it's just going horizontal?* Rachel directs Anita to think through her choreography: *I would watch it and try to fuzz out your eyes and just look at tempo and duration because for me it needs to tighten up a bit. And I think that you have everything you have and you just need to tighten it up in some spaces and then it's actually gonna fit your music and you don't have to worry about it. There's a couple of places where it just slows down too much.*

Table A2. Teaching as improvisation codes with examples.

Teaching as Improvisation Codes	Examples
Breaking the 4th wall: Breaking a student-teacher interaction dynamic to settle a conversation at the end of its allotted time or meta-communicating an important point such as a concept or "ground rule" that has intrinsic value for the person or field of inquiry.	Rachel encourages Elena to assess her current choreography in relation to her original intentions – meta-communicating an aspect of reflective practice: *I think you're in your situation, your optional situation right now is that you started with an idea that generated movements and generated your staging and everything. Um, and I think that what happens is we work and then we create something and that thing speaks, and I don't think it's necessarily saying like straight your ideas that generated it. So for me, the optional situation, and then seeing women like half-dressed in underwear, I don't understand what you're trying to tell me and I don't go to the place that you started from. And I'm not advocating for you pushing your piece in the direction of the ideas you started from, because ideas are generative, right…because these ideas about pulling the clothes may not have anything to do with your ideas about worry, right? But the piece is maybe calling for that to happen. So you just get to decide, like do I stick and go into like I want it to be like this, and make changes and push it more towards an original idea or do you flow with what is happening and go, you know, I can let go of some of my preconceived notions and follow the flow.*
Denial: Breaking a student-teacher interaction dynamic by rejecting what another has introduced into a dramatic frame or performance space (the opposite of the *Yes, and* code).	Claire rejects Elena's title of "Optional" for her choreography: *So, the title is fine but for me it's not 'optional', so I'm just – it doesn't mean you have to change anything but I'm confused by 'optional' in what I see.* Nelson rejects the Robot Fish team's idea of using silicone to seal a watertight PVC tube: *And so using RTB or silicone. Ah, it won't be too efficient for you if you have to pull it off - and then go in there and then reseal it and wait for it to dry and then pull it off.*
Driving: Taking over a student-teacher interaction, not letting others talk or contribute (video may need to be reviewed for corresponding physical cues such as pauses, body language, authoritative tone, etc.).	Although Todd starts to talk about another idea, Gary drives the conversation to stay with the first idea: *Well, let's stay on this. Maybe you changed your form. Let's modify this form to where maybe it's upholstered or could have maybe more massive forms. Ah, 'cause this is kinda neat how this all works together. Maybe you – what you do is you play – work backwards – from this. Find that a form which maybe you stay away from, but being real thin areas, bulk it out a little bit. Yeah, this is, this is pretty neat. This would be great.*
Yes, and: Affirming what another has introduced into the dramatic frame or performance space (such as accepting an assertion or building on an assertion), allowing a student-teacher dialogue to emerge and flow.	Mia builds on what Claire expressed about Elena's first performance: *Um, and just to piggyback what Claire was just saying about the sleep thing is that it's almost like they're dreaming about sleeping like they're going through their workday and like 'I wish we could go home and take a nap' and so if your piece is going to have a linear progression it would totally work because you know how often do we think about 'oh, it would be nice to lay down,' [laughter] you know and so I was just thinking that that's just an idea to help you…* Nelson asks the students to share why they didn't stay on schedule – a student responds and Nelson affirms his explanation: Nelson: *Alright, so why did you not stay on schedule? I mean really.* Student*: The actual building, assembly, and all that stuff, didn't take as long as anticipated, but the design took longer….We realized as we were getting behind schedule that we were still in that part, and then the next part wouldn't probably take long.* Nelson*: Okay. So that's actually, a good reason. If you recognize the complexity of the different phases and you adjust for that, then that's a good idea.*

Table A3. Design judgment conceptual knowledge codes with examples.

DESIGN JUDGMENT CODES	EXAMPLES
AESTHETIC: Artistic appeal (e.g., visual, auditory, and sensory), aesthetic principle (e.g., authenticity, simplicity, purity, etc.) or embodying a sense of beauty (shape, color, rhythm, texture, symmetry, contrast, organic, space, variation, juxtaposition, etc.).	Glen praises the aesthetics of visual appeal, negative space, tectonic imagery, and tension observed in one of Todd's concepts: *…there's something nice about that triad….Visually, it's really attractive….I like this just because you created some negative space...Tectonics and everything…I saw that neat little tension. It creates tension which is kind of neat.* Rachel praises the aesthetics of juxtaposition observed in Elena's first performance: *Um, the breathing line is another interesting juxtaposition of formalism and this like human, like a very human quality and I guess that was the thing of I liked the really humanness…* Nelson asks the Robot Fish team if a goal of their final solution is to make it look authentic: *So were we gonna finish the outside, paint it, make it look like a fish?*
COHERENCE: An integrated or cohesive system, a sense of completeness, or embodying a designer's perspective or passion.	Gary discusses the coherence of Todd's design and how the essence of the form may change once he formalizes the dimensions: *Cause you may lose the essence – design essence and what you're passionate about. Formalizing it may just all go away…when you fit it into their requirement of seating height…* Mia describes how a feature of Elena's first performance brought the piece together: *Um, for me probably that most, uh, the poignant moment, like what kinda brought your piece together for me was when Amy and somebody, they just went like this…The backbend, it just brought it all together, you only need two people doing it and it was just, um, crystal clear…* Nelson asks the Robot Fish team to clarify how one feature of the solution interfaces with another feature of the system: *So doesn't it also translate when you turn the servo arm. If it's on the end of the servo arm, doesn't that rod translate?... How can it rotate if it's got a fixed pole in the body?... There's a slide. Okay. I've got it.*
FEASIBILITY: Feasible technical or human performance, or viable (e.g., easy to afford, easy to realize or make).	Claire refers to the feasibility of a possible choreography movement in Anita's first performance: *I don't know she might, is there any way that her foot could pop out over a person's shoulder up here, like is she that flexible?* Nelson refers to the feasibility of two aspects of the Robot Fish team's design – water tightness and the moment on the servo arm: *Yeah, I got two concerns. One is the water tightness of the PVC. I think you need to make sure you got O-ring seals because you're gonna have to go in and out of that a number of times…Looking at that servo again, if this is an accurate representation, I don't think that moment arm's going to rotate that. You might check that - with the relative position, I realize the picture might not be accurate….But it looks like in an extreme location, I don't think it's going to work, but just check it to make sure.* Gary encourages Todd to test the feasibility of his design: *I'd make sure that this thing does function….Talking about get a dowel and drill through the bottom all the way up…and see if it actually functions.*
INTERACTIVITY: Practicality or experience of a design (e.g., ergonomic features, easy to use, multi-functionality or adaptability to different situations, enjoyable, etc.).	Gary asks Todd about how one of his ideas would be used and if it will be comfortable: *Now keep in mind you pull it off, where's it gonna go? Is it gonna go down pretty much, stand on it…You gotta think about the user interface and how you'd do that, how it peels back, 'cause you don't want it to be uncomfortable piece of fabric…* Mia brings up a concern about how easy it will be for the audience to make sense of a particular feature of Anita's choreography: *My concern with that is you're not gonna*

	be able to read it from the audience. Nelson asks the Robot Fish team to clarify how someone would use their solution: *How do, how does it initialize…Where is the On/Off button?*
NOVELTY: Unique, evolutionary, opens up new markets or meets future needs.	Gary communicates to Todd how one of the goals of the project is to be original: *…you didn't want another "me, too", like want something original…'Cause your job, your job is to bring something exciting into the workplace…* Rachel praises Elena's choreography for not following the norms: *Uh, it's a weird little piece. [Chuckle] It's like this is a weird little piece - you know, in a good way like it doesn't follow a lot of norms and so I appreciate that.*
(UN)PREDICTABILITY: A dramatic, unexpected, unpredictable, or counterintuitive experience (an aesthetic goal); in contrast, a sense of certainty or predictability (a feasibility goal).	Gary praises one of Todd's designs because it creates a sense of surprise: *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…* Sophie praises Anita about how her choreography was unexpected: *…you push me to see something that's not what I expect, in terms of structure. Like, I don't expect you to have a slow section when you have it and I don't expect you to move when you start moving. Um, you've thrown me off a little bit, you know, I like that. You did that in your other pieces too. Um. So you know, it challenges when I watch it. It forces me to kind of stretch a little bit…* Nelson asks the Robot Fish team if they checked an aspect of their design: *We predicted that, right?*

Table A4. Task and process management procedural knowledge codes with examples.

TASK CODES	COACH ENCOURAGES AND/OR DEMONSTRATES BEHAVIORS TO HELP A STUDENT…
PROBLEM FRAMING: Comprehend important features of the problem. May discourage or counteract behaviors such as treating design as well-defined and prematurely attempting problem-solving.	Gary encourages Todd to consider what the client wants: *So as the designer, the client wants you to come in and – this is what I perceive that they want - If you were the designer from one of those other kinda traditional ottomans, what would the next level be…they can't be a 'me, too'. So what's gonna attract 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…So that, that's what they're looking for, something, something new and exciting.* Claire asks Anita to explain the purpose of her choreography: *Like, Martha Graham is good with formalism and emotion at the same time, so maybe I'm kind of like – I was just wondering, do you want to pull us into that place where gestures have meaning or are gestures abstract?*
DOING RESEARCH: Learn about the problem or how the system works. May discourage or counteract behaviors such as skipping doing research and building solutions immediately.	Gary encourages Sheryl to do online research on ways she could attach one feature of her design to another: *…maybe get online, look at outdoor furniture pieces or whatever they have posts and attachments, 'cause it's gotta be attached because when you put your section down you can't have anything sticking down.*

IDEA FLUENCY: Generate and work with lots of ideas. May discourage or counteract behaviors such as working with few or just one idea, which they can get fixated or stuck on.	Gary praises Todd on the kinds of inspiration he drew upon when developing his first concept ideas: *So you have the ice cream cone, now this is your cake thing…Good inspiration.* Mia encourages Elena to consider different options for communicating panic through breathing: *…as Clair was saying you know different kinds of breathing, sighing, you know the panic with the trying to catch your breath or trying to slow your breath down, that might be helpful too to help find your rhythms…* Anita explains to the coaches that she has tried to push herself to keep coming up with new ideas: *And I don't really feel like I have any structure, like, as far as like how it's flowing in and out of it because I've really just been pushing myself to keep creating all the way up until this point.*
DEEP MODELING: Inquire into how ideas work, function, or could be made (e.g., prototyping). May discourage or counteract behaviors such as superficial drawings or models.	Gary encourages Todd to model his ideas to he can evaluate them in real scale: *I would develop these in terms of scale…and you may find out that it also may force you into some other forms you like even better. So by this time next week…I wouldn't mind seeing a scaled elevation front and a side view and a top view. I mean, I'm talking about just taking a piece of paper and creating a grid on a piece of paper over it, and then – nothing major…I just wanna make sure that you're going down that route to where you evaluate in terms of the real scale* Nelson asks the Robot Fish team to explain an aspect of their design that is not well illustrated in their drawing: *The servo, it doesn't show in this view so well, but isn't that pivot rod offset from the centerline of the servo? That, ah, axle that turns the fin. Yeah, that guy. Is that not offset from the centerline in the servo?* Hannah encourages Elena to experiment with different gestures that communicate the experience of being on the subway (in the video she gets up and physically models options): *Um, play around with different hands, so what is it to you? Is it subway?….Then maybe it's how their weight is…um how they're…They need to go on the subway.*
BALANCE TRADEOFFS: Judge options and make decisions that acknowledge both benefits and tradeoffs. May discourage or counteract behaviors such as attending only to pros or cons.	Gary encourages Todd to consider multiple goals (simple, form, unique) to help him select the five or six ideas he would like to keep working on for the next review: *So keep it – again, keep it simple. Play up the forms. Look at what the competitors are out there. Do something unique….And if you – with that in mind, what would be your five or six….that you would want to, to work on?*
VALID EXPERIMENTS: Conduct valid experiments to substantiate design decisions. May discourage or counteract behaviors such as doing few or no tests on prototypes, or running confounded experiments that cannot provide useful information.	Gary encourages Todd to test the feasibility of an idea and offers a way to test how it functions: *Talking about get a dowel and drill through the bottom all the way up, and, and then, with a drill press and then, get a dowel and see if it actually functions.* Claire encourages Elena to experiment with different ways to capture the experience of a sudden stop: *But it's like I would love for your dancer to take some time and just do it a couple times like somebody had a string and all of the sudden stopped her….and you ran into something and just see, experience how your body does….torque a little bit….and bring that richness to that stuff that she's got….Um, so it's more natural.* Nelson encourages the Robot Fish team to test a feature of their design to determine if it would break: *One inch. So you're putting a pretty large moment on that servo. And we calculated that?...You might check that with the relative position, and I realize the picture might not be accurate….But it looks like in an extreme location, I don't think*

	it's going to work, but just check it to make sure.
FOCUSED DIAGNOSTICS: Identify problematic aspects and propose ways to improve, fix, or build on them. May discourage or counteract behaviors such as unfocused and non-empirical diagnoses that cannot provide useful information for improvements.	Gary encourages Sheryl to prototype a feature of her solution so she can assess if she loses the visual essence of her design: *This is intriguing, but I think what I would do is I would maybe – this is gonna change because you gotta change some of your dimensions….See what it looks like, develop that far enough to where if you start losing the essence of what you consider a strong visual design*. Claire encourages Elena to experiment with an aspect of her choreography and offers a suggestion for improving the "braking" movement: *Um, I love how they put the brake on or I said 'they're putting on the brake' when you stopped them and, I was just so interested in that and I was wondering if you could find other ways of that being stopped in your tracks kind of feeling, like what would happen if it was part of a turn and all of a sudden you stopped in the middle of the turn just to explore that you know, the brakes.* Nelson encourages the Robot Fish team to increase the length of the moment arm on the servo motor to improve an aspect of their design: *Okay. So technically, that should right itself, right? But it's gonna be really slow….So we might want to think about trying to increase that distance, that moment arm.*
MANAGED ITERATION: Do design in a managed way where ideas are improved iteratively through feedback. May discourage or counteract behaviors such as designing in haphazard ways or having a linear process.	Gary encourages Todd to be open to the benefits of being open to change: *And you may find out you gotta change it, which may lead even lead you a better solution…* Rachel encourages Anita to be open to making changes to her choreography to improve the experience: *Well, there's plenty of time to try – I mean the piece itself might be fine that your movement keeps it from being heavy but there's still time to change your sound, like add another element to your sound, to lighten it up or – you know, there's lots of approaches to how you can keep it from all feeling in the same family if you don't want it all in the same family…* Nelson encourages the Robot Fish to identify improvements to their design: *If it is not fully functional, what is not working and why…which will lead you into how do you fix it, probably….Ah, improvements*.
REFLECTION: Reflective practice (e.g., listening to "situation's backtalk", self-monitoring behavior, assessing the value or relevancy of design strategies). May discourage or counteract behaviors such as tacit designing with little self-monitoring or not being open or willing to reflecting on past.	Rachel encourages Elena to step back and reconsider her goals in relation to the current design: *Um, and I think that what happens is we work and then we create something and that thing speaks, and I don't think it's necessarily saying like straight your ideas that generated it…So I think it's really hard to step away from your work and just ask it, you know, what are you doing…and how can I help bring that to fruition. Because I think it – for me, I think it has a different title than, than how you've got it right now.* Gary asks Todd about what he is taking away from the recent client review: *I think they like my mockup more than these shapes…It tells me I should refine it*. Nelson asks the students to share what they learned over the course of the project: *So just for my own, ah, information, tell me some of the things that you actually learned during the course of the project…How about the schedule since we put so much emphasis on schedule? What did you get out of that?*
PROCESS MANAGEMENT CODES	COACH ENCOURAGES AND/OR DEMONSTRATES BEHAVIORS TO HELP A STUDENT…
COMPLEXITY MANAGEMENT: Manage complexity such as revisiting or negotiating	*Gary encourages Todd to focus on developing his simpler ideas first*: And you may find out that, you know, in fact, what I would do is I would do the easy simple form ones first, and the more complex ones later – 'cause you're gonna find out on your forms whether or not it's something you wanna work with…

scope of work, and assessing feasibility within a timeline.	Nelson affirms a statement from a student about how you have to adjust time schedules for the complexity of tasks: *So that's an – actually, a good reason. If you recognize the complexity of the different phases and you adjust for that, then that's a good idea.*
RISK MANAGEMENT: Anticipate and attend to risks associated with planning, communicating, or developing a design.	Gary encourages Todd to always have a "safe" design to enhance his potential for success: *Always do something safe…there's a good reason for the safe, too, is what it does if you don't have the option – I call it the illusion of choice. If you don't have that option and they see all you're really extreme, they don't have anything that's gonna ground 'em to why they like what you like… So if you give them an option, you can fall back on this…* Mia encourages Anita to explore options for an aspect of her design "just to be safe": *But I understand what you're saying about softening that, so anyway, but I would think about other ways to do that or something. I think just to be safe…* Nelson encourages the Robot Fish team to run a kinematic analysis to make sure the design will work as expected: *But it looks like in an extreme location, I don't think it's going to work, but just check it to make sure….You know, go through the kinematics of it to make sure it works, like in Solidworks to cycle it back and forth….Again, it looks – intuition tells me it's not gonna work, but – go ahead.*
TIME MANAGEMENT: Manage time to successfully complete tasks within a prescribed timeframe.	Gary offers strategies to help Todd effectively use his time: *And what I would do, once you decide which ones you're working on, I would spend – give yourself a cutoff. Give yourself say a couple hours on one. This weekend's really important for you on this project…to me a secret of about good design is having a consistent body of time to focus, if things get broken up because of your class load and everything, and you're always stopping and starting…* Hannah praises Anita on being on schedule with her project: *You're at a good place….For this showing….Because it feels like you've gotten a lot done, costume wise, dance wise, like every which way, like you're at a good place to be done.* Nelson offers strategies for staying on schedule: *The solution, to maintaining schedule is never tell your team working for you what the true schedule is. Always put a buffer in it, and never tell them. Because it is human nature for them to overrun to some extent, and you must have, as the leader, you must not overrun your schedule. So you have to put buffer in it.*
MULTIPLE PERSPECTIVES: Manage plurality of perspectives to develop own perspective and having a tolerance and appreciation for ambiguity.	Gary acknowledges the possibility of different perspectives to Sheryl: *So, of course, if you're a designer, you see all sorts of, of different elements you could take it…* At various times, the choreography coaches explicitly expressed that as a group they did not always share the same perspective. For example, Claire reacted to a comment from another coach: *That's a really good comment but I didn't get any of that.* Rachel reacted to comments from the other coaches about Anita's choreography to express an alternative perspective: *And I just wanted to add that I realize that I haven't really haven't look at them as women at all. I just look at them as beings like just like, just to offer that, that they're like blank because of that so that they're wearing leotards and all that stuff and so I don't like look at them as like women. I categorize them as dancers more and so I think about them as – and think of it as a form piece pretty strictly just to put that out there.* Nelson asked students to share if they agreed with a comment from another student: *Is this the same answer for everybody do you think? Would you all, all agree to this*

	answer? [This student] says that's generally the answer. Do you all agree with that?
SUGGEST DON'T TELL: Exercise and have agency in design judgment under ambiguous circumstances.	Gary encourages Todd to be "the final decision-maker": *...you're the final decision-maker on this. I'm just here to help you along if I can…I'll make my suggestions and you figure out what you wanna do with it.* Sophie encourages Elena to disregard her feedback if it goes against what she wants: *…if that's what you want. If not, then you know, you can just you can disregard what I just said.* Nelson encourages the Robot Fish team to think about making a change to their design: *All right, so you might want to think about moving the pivot point to the center of pressure so that moment arm is reduced.*