STUDIES IN ENGINEERING EDUCATION

Professor Talk in Undergraduate, Introductory Design: A Multiple Case Study from Mechanical and Biomedical Engineering

EMPIRICAL RESEARCH

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ABSTRACT

Background: Introductory design projects are an influential and important time to introduce students to engineering in authentic and engaging ways in order to prepare students for their future academic and professional careers. Instructors must be able to scaffold their students to reach more advanced design skills. However, the most effective ways to do this, specifically how instructors use their talk with students, are not well understood.

Purpose: We aim to address the research question: How do instructors interact with students and use their talk as a tool to scaffold undergraduate students' learning during their work on engineering design projects in introductory engineering courses?

Design: We employed a multiple case study approach to examine the content of three professors' talk during introductory engineering design projects, guided by a theoretical framework based on the components of scaffolding.

Results: The professors took on a role as a guide or mentor to students during their projects, with differing goals for their mentoring. In light of the introductory nature of the design projects, the professors focused primarily on non-technical content, including iteration in design, teaming, and communication, but pointed to technical applications of their ideas in future projects. They supported some challenges for beginning designers but were not comprehensive in their support of others.

Conclusions: The professors in this study are experienced engineers and teachers with valuable experience. They used their experience to act as more knowledgeable others to mentor students and excite them about their engineering careers. However, there were some disconnects between the professors' values in design and their talk with students, such as in learning from failure and problem scoping. These findings support the need for support for instructors, specifically in how to more closely align their talk with their teaching goals.

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High-quality instruction is not only essential for student learning, it is also an important aspect of retaining students and engaging their interest in STEM fields (Engberg & Wolniak, 2013; Marra et al., 2012). Low-quality teaching of undergraduate engineering students leads to frustration, dissatisfaction, and struggle with engineering, especially for underrepresented groups in engineering (Blair et al., 2017). The first year of college, as students are introduced to the discipline of engineering, is an especially key time to introduce students to engineering in positive and realistic ways that will set them up for future success (Froyd et al., 2012). Specifically, the ways in which students interact with their professors have been shown to influence students' perceptions of engineering and their persistence in STEM disciplines (Jones et al., 2014; Watkins & Mazur, 2013). However, the most effective ways for professors to interact with students during engineering design are not well understood. Therefore, in order to better understand effective teaching strategies during undergraduate introductory engineering design courses, this study examines one aspect of pedagogy, teacher talk, to address the research question: How do instructors interact with students and use their talk as a tool to scaffold undergraduate students' learning during their work on engineering design projects in introductory engineering courses?

BACKGROUND LITERATURE

Introductory undergraduate engineering design projects have an important role in introducing students to the field of engineering and framing their learning experiences. Instructors' roles in design projects have unique challenges, and the ways in which teachers talk to their students frame their design experiences and learning.

INTRODUCTORY ENGINEERING DESIGN

Introductory engineering design courses, sometimes called first-year design or cornerstone design, play an important role in introducing students to the field of engineering (Froyd et al., 2012). Students enter college and introductory engineering courses with vast arrays of experiences, interests, and ways of knowing, from both their formal and informal education, which affects their conceptions of engineering, how they define and contextualize problems, and their academic preparation (Kilgore et al., 2007). These prior experiences provide students with some knowledge about engineering design processes that introductory courses can build on (Mckenna, 2007). However, early design experiences have direct effects on students' design thinking, how students prioritize components of engineering design, and their conceptions of engineering (Jones et al., 2014; Williams et al., 2011). Additionally, introductory design experiences are correlated with increased intellectual and cognitive development and retention (Knight et al., 2007; Marra et al., 2000), in part because of hands-on activities, development of community, mentoring from professors, and links to the ways they can use engineering in causes they care about (Knight et al., 2007; Lara-Prieto et al., 2019; Taheri, 2018). However, how to implement these strategies effectively into classrooms is not fully understood.

As will be described in the theoretical framework section, instructors work to scaffold their students towards more being more advanced designers. Therefore, they must understand both where students are coming from and where they are going in order to most effectively guide students there. First-year engineering students conceptualize design and use design strategies differently than experts, differences that have been well documented in the literature (e.g., Atman et al., 2005, 2007; Crismond & Adams, 2012). For example, compared to experts and more advanced students, novice designers often do not spend as much time on problem definition, often become fixated on an idea early on, and do not use as much evidence to define their decisions (e.g., Adams et al., 2003; Atman et al., 2005; Crismond & Adams, 2012; Gero, 2011; Mckenna, 2007). Additionally, compared to more experienced designers, first-year students are not as reflective about their design practices and must learn to use skills such as self-monitoring, clarifying, and examining in order to learn design and communicate their ideas effectively (Adams et al., 2003; Deveci & Nunn, 2018). Although a variety of factors that are not limited to things within an instructor's power play into how students overcome these challenges over the course of their education, instructors should be aware of these challenges to best support their students' learning in design so that they can tailor their instruction to helping students to improve their skills in engineering design.

INSTRUCTOR ROLE IN ENGINEERING DESIGN EDUCATION

Instructors play a vital role in helping to guide students towards more sophisticated design processes and developing their conceptions of engineering. Introductory design courses directly affect student's perceptions of engineering and the types of problems engineers solve (Jones et al., 2014). Many courses that first-year engineering students take are focused on analytic, well-structured problem solving, rather than open-ended design. Therefore, it is an additional challenge for instructors of design courses to support students in their thinking across these different types of problem solving (Lande & Oplinger, 2014). There has been limited research on the specific ways to support students in the classroom-based projects that are typical of first-year design courses; however, there has been research on pedagogies and instructor roles in other contexts of teaching design, such as senior level design reviews, that can be used as a starting point to improve understandings of how instructors can support their students during engineering design projects.

One important role of the instructor is to act as a mentor or guide to students as they are working on design projects (Paretti, 2008). Several studies suggest that for students to authentically engage in design, instructors should act more as coaches or tutors, rather than the end all expert in the classroom (e.g., Dannels, 2002; Oak & Lloyd, 2015). For example, McDonnell (2016) described how an experienced designer guided student designers through the design process by acting as a project manager, giving the students structured tasks and direct support of technical knowledge, but pushed them to make their own design decisions. Some common challenges related to mentoring students in design include balancing team dynamics, focusing on supporting learning of the design process versus the final product, and balancing technical practice with professional skills practice (Paretti et al., 2011). The skills needed to guide students through these challenges are different than those needed to develop technical content mastery (Pembridge & Paretti, 2019). Additionally, the instructor often has a different level of power than the students and instructors' ideas are often readily taken up by students, which could affect the agency students have for their design ideas (Svihla, et al., 2021).

Another important role of the instructor in introductory design projects is to support students to overcome challenges in design, such as those typically experienced by beginning designers (Crismond & Adams, 2012). For example, one such challenge is overcoming idea fixation and learning to effectively brainstorm. Sio et al. (2015) found that when instructors provided examples, students were able to generate more example-related ideas and higher-quality ideas. However, providing examples also limited the number of categories of student ideas. Additionally, in order to learn design, students must be exposed to both the knowledge about design and gain experience with the skills needed for design (Christiaans & Venselaar, 2005). Therefore, the instructor should provide experiences that allow students to progress through the entire design process and apply different types of design knowledge.

Since first-year engineering design courses are often students' first experience with engineering design, instructors of introductory courses have a role to provide an authentic experience that gives students accurate pictures of what engineering design is. Instructors of these courses also have a role in helping students see themselves as engineering designers and gaining confidence and identifies around engineering design. The ways that teachers carry out these activities in their classrooms is structured by the ways that they talk to their students.

TEACHER TALK AND DESIGN

Communication, including communication between teacher and student, plays a vital role in how students learn design thinking and doing. The ways that teachers approach teacher-student communication and the things they say to their students influence how students design. For example, if an instructor proposes a solution to a design problem, students often take that as advice and tend to follow it, limiting the scope of their potential solution or, if the teacher gives positive feedback, students often take assume they have found the best solution (Dong et al., 2015). Therefore, instructors must be careful in both their positive and negative comments on designs. Additionally, the ways that the instructor uses talk to set up the classroom and design challenge affect students' design processes. For example, in giving specific instructions related to problem framing, the instructor influences how students think about design as either a piecemeal of smaller activities or as an integrated design process (Secules et al., 2016). When "the language of engineering design…is oriented to the design process," rather than the solution itself, students more clearly see the importance of engineering design as a process, "rather than knowing engineering design as a set of solutions to a problem with few or no events in between" (Atman et al., 2008, p. 318). Therefore, instructors have the careful task to monitor what they say to match the needs of the students at the time of the interaction.

THEORETICAL FRAMEWORK

This section describes the theoretical framework used to guide the analysis of the professors' talk. The theoretical framework is built on the foundation of Vygotsky's work (1978, 1986). From this work, we know that teachers act as a more knowledgeable other in the classroom, guiding and scaffolding students towards development of skills and knowledge needed to understand concepts that they cannot do alone (Vygotsky, 1978, 1986). Teachers use a range of pedagogies to support their students, which are framed by the way they use their talk to portray ideas to their students (Scott 1998). This work has been extended and further defined by others to encompass the theory of scaffolding, as described below.

There are three major components of scaffolding on which the research is consistent (van de Pol et al., 2010; Wood et al., 1976). First, there must be *contingency*, meaning the teacher's support must be adapted to the student's level. Second, there must be *fading*, by the "gradual withdrawal of the scaffolding" through decreasing "the level and/or amount of support" over time (van de Pol et al., 2010, p. 275). Finally, there must be *transfer of responsibility*, "that is, responsibility for the performance of a task is gradually transferred to the learner" (van de Pol et al., 2010, p. 275). Even within these three overarching aspects of scaffolding, there are different forms, including designed-in scaffolding and contingent scaffolding (Sharpe, 2006). Design-in scaffolding involves "the overall design of the unit of work to achieve specific outcomes including the sequence of tasks within each lesson and types of resources to be utilized" (p. 213). Contingent scaffolding is "contingent on the circumstances" and refers to when the teacher takes advantage of point-of-need opportunities, using "a variety of discourse strategies such as questioning, recasting or relating to students' previous experiences" (p. 213) to interact with students in the moment. One of the key aspects of scaffolding across all types of scaffolding is the timing of the support (Vygotsky, 1986). There are certain periods of optimal learning that teachers can capitalize on because "during that period an [instructional] influence that has little effect earlier or later may radically affect the course of development" (p. 189). Additionally, teachers must balance the technical content instruction with the language instruction needed to support the concepts, and if language used in scaffolding is too narrow, it may limit the students' abilities to transfer their knowledge to new contexts (Jung, 2019).

The ways that professors talk to their students set up the scaffolding to introduce students to disciplinary language and ways of thinking to understand concepts that are in their zone of proximal development. This study utilizes this theoretical framework to examine the talk of three professors during introductory, undergraduate engineering design projects. Each case study is framed around the specific talk strategies each professor uses and the cross-case synthesis looks holistically across the cases using the theoretical framework. Specifically, our analysis will show how different instructors utilize the different components and aspects of scaffolding we describe here.

METHODS

This study uses a multiple case study approach (Creswell & Poth, 2018; Yin, 2018) to look at the teacher talk strategies of professors of undergraduate introductory engineering courses during design projects. The purpose of case study research is to develop an in-depth description of a bounded system, which must be a case or cases that are chosen with purpose. The cases in this study were chosen to represent engineering professors who engage in varied types of verbal

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interactions with their students, including but not limited to discussions with the whole class, interactions with individuals and teams of students, and questions asked by both the professors and students. The analysis and written descriptions of each case cannot be separated from its context, so case studies use multiple sources of information, including interviews, observations, and documents to develop these descriptions (Denzin & Lincoln, 2018). In this study, each bounded case is the classroom talk of a professor during engineering design projects. Case study methodology has been used in other contexts to study communication between instructors and students in design (Paretti, 2008). Each descriptive case study (Schwandt & Gates, 2018; Yin, 2018) focuses on analyzing data from all aspects of the case to provide an in-depth description of each of the three cases of professors' talk interactions with students during engineering design projects along with a cross case synthesis across the cases. IRB approval was gained from the university before any data was collected and all participants gave informed consent.

CONTEXT

This study was conducted at a large, public university focused on undergraduate teaching in the western United States. The College of Engineering at the university has the largest enrollment with 6,000 students, of which 83% are in-state students and 1% are international students. The student body is 55% white, 17% Hispanic/Latino, 13% Asian American, 8% multi-racial, 4% unknown/other, and less than 1% each African American and Native American. At the university, 48% of the students are women and 52% are men. Twenty percent of students receive Pell Grants. For first time freshmen, the College of Engineering has a 23% acceptance rate, and the university has an 82% six-year graduation rate. The size and gender demographics of each class focused on in this study are presented in Table 1. This was the only demographic information that was collected from the specific classes studied.

Table 1 Demographics of each professor's class.

PROFESSOR	ENGINEERING DISCIPLINE	TOTAL NUMBER OF STUDENTS	PERCENTAGE FEMALE STUDENTS
Davis	Mechanical	23	39%
Pfeiffer	Mechanical	23	30%
Wilson	Biomedical	30	53%

Cases

This study focuses on three professors, Professors Davis, Pfeiffer, and Wilson, all pseudonyms, who each taught introductory courses for their disciplines that included the students' first experience with engineering design at the university. Two of the cases were mechanical engineering professors and the third case was a biomedical engineering professor. The courses were chosen because they were the first course in each major to include a design project. Although the biomedical engineering course was taught to sophomores and the mechanical engineering course was taught to first-year students, the learning objectives and purpose of the courses were similar, specifically to introduce students to the field and involve them in an introductory design project. For the mechanical engineering course there were three instructors teaching the introduction course during the term of study. Two of the instructors agreed to participate in the research and the third did not want to participate. For the biomedical engineering course, the instructor chosen was the only one teaching this course during this term. Each of the three professors have different experiences and ways of teaching. This section presents a brief description of each case, utilizing quotes and information from their pre-interviews. Further descriptions of each professor's experiences and teaching views are included in the results section along with examples from their teaching that tie into their experiences. Demographic information for the three professors is displayed in Table 2.

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PROFESSOR	YEARS OF TEACHING EXPERIENCE	RANK AT THE UNIVERSITY	GENDER	ETHNICITY	NATIVE LANGUAGE
Davis	>20	Professor	Male	White	English
Pfeiffer	>8	Assistant Professor	Male	White	German
Wilson	>5	Assistant Professor	Male	Black	English

Table 2 Demographic information for each professor.

Professor Davis is a professor of mechanical engineering with more than 20 years of experience teaching at the university. Prior to teaching, he worked in the aerospace industry for several years. Professor Davis has previously taught the first-year course studied in this study and the junior and senior level design courses in the department. When he first began teaching, he took several classes through the university's center for teaching and learning. He has had no other formal teaching education.

Professor Pfeiffer is an assistant professor in mechanical engineering. He has taught first-year courses at this university and his previous institution several times, as well as a senior design course. In graduate school, Professor Pfeiffer earned graduate teaching certificates that required analysis of his teaching and has continued to engage in teaching workshops. English is not Professor Pfeiffer's first language.

Professor Wilson is an assistant professor in biomedical engineering. He has taught at the university for five years and taught in small amounts before coming to the university. Prior to that, he had extensive experience in industry with several large medical device and chemical companies, including teaching short courses. When asked about his teaching education, he said "all my coursework has been engineering and business […] I never, come to think of it, I haven't had a teaching class."

Mechanical engineering course format

The format for the mechanical engineering courses taught by Professors Davis and Pfeiffer was similar across the classes. Each class met once per week in a small lab section (24 students or less) for three hours. Additionally, a larger seminar (90 students) met once per week for two hours. Although Professors Davis and Pfeiffer each taught multiple lab sections, this study focused on one of their lab sections each. The two sections focused on in this study were taught on different days, but at the same time of day and in the same classroom. Professor Pfeiffer was the instructor for the seminar class; however, during the design project, Professor Davis attended or cotaught the seminar class most days that the students were engaged in the design project.

For both mechanical engineering classes, the design projects were conducted entirely during class time, with the exception of the initial homework assignment. The deliverable for the project was a poster that was presented at a design expo on the final day of class and evaluated by the students' peers. The design project was developed primarily by Professor Davis with input from Professor Pfeiffer. In addition to the major design project that is the focus of this study, each class engaged in a short design project to build a spaghetti tower on the first day of class. These class periods were not recorded because it was not possible to have student consent on the first day of class.

The design project was introduced in the lab sections with a homework assignment in which students were given the design problem, asked to brainstorm at least four potential ideas, and complete a skills self-assessment. The skills assessment asked students to rate their skills in creativity, leadership, organization, communication, and artistic ability. The design challenge that the students were given was:

> We are asking you to design something that could help people with physical challenges to improve their accessibility to some activity. It will be up to you to identify the physical challenge and the activity you are addressing. Example: Design of playground equipment to increase accessibility for people that use wheelchairs.

The students were given a graphic of the engineering design process and asked to complete the first two steps individually with the following prompts:

> ASK: Do you understand the problem at hand including the objective and the constraints?
>
> IMAGINE: You are to contemplate the challenge, think about possible solutions. You want to generate as many solutions as possible. Do not evaluate yet! If one of your ideas does not include a nuclear reactor you're probably not getting crazy enough! Now filter down your ideas to the best ones that you will develop further and write up for class.

During the subsequent lab meeting, the students got into teams based on their ideas, each professor used a different method to form teams (described later in the results). During this same lab period, they worked with their teams to prototype their ideas. In both classes, they were asked to continue to consider multiple ideas.

During each of the following two seminar sections, the students had one hour to work with their team on their design projects. Finally, students had the entire last seminar and lab sections of the term to work on their projects resulting in a total of 10 hours of class time devoted to the design project. During the final meeting of the course, there was a design expo in the format of a poster session.

Biomedical engineering course format

The biomedical engineering design project was conducted as a small part within an introduction to biomedical engineering course. This course was taught primarily to sophomore students but was their first experience with a design project at the university. This course met once per week for one hour and the purpose of the course was described as "introduce the fundamentals of bioengineering design. Some areas of discussion will include biomechanics, biomaterials, pharmaceutical and medical device design, cardiovascular disease, and intellectual property." Most class periods focused on particular topics within biomedical engineering practice. One of these class periods focused on the design project, students were expected to complete the rest of the project on their own time. Their design projects were very open-ended. They were asked to come up with an idea to solve a problem within biomedical engineering, without any other constraints.

During the class period in which the students worked on the design project, Professor Wilson introduced the project by giving an example of a senior design project. He then used this example to walk the students through the design process and described which parts of the more thorough senior design project they needed to do for their smaller design project. They were then given graphic organizers to organize three different ideas. Outside of class, they were expected to continue with one of these ideas to produce a deliverable of a short presentation for a design expo. This design expo was conducted in a different course, Professor Wilson was not directly involved.

DATA COLLECTION

The first step in the data collection process was to observe each potential case prior to the design project to better understand if there were sufficient opportunities for professor-student verbal interactions during the data collection period, to start to understand the classroom environment, ensure that the equipment worked, and explain the project to the participants and gain their consent. Additionally, before any classroom observations, each professor was interviewed to obtain information about their educational background, how much and what types of teaching experience they had, what teaching professional development they have had, and some information about their views on teaching style. The primary purpose of these initial interviews was to gain further insights into the professor's teaching and thinking to more fully understand and describe each case.

Classroom data were collected throughout the length of time that the students are working on the design project in class and consisted of video recordings of the classes, field notes, pictures, and interviews with the professors. The primary researcher attended each class with a video camera and transmitter that allowed sound to come directly from the professor. The researcher sat in an inconspicuous location so as not to disrupt the class and recorded field notes throughout the class. The field notes recorded general notes about what happened in the classroom and time stamps for transition points for reference against the video recordings later. Additionally, key moments or aspects of the professor's talk were noted for later analysis as well as any questions for the professor and specific points of dialogue to probe further. After each class period, an informal conversation was conducted with the professors to ask these questions to better understand what the professor was thinking at the time and gain further information about the interactions. To aid in the development of the trustworthiness of the study, the data collection consisted of multiple sources of evidence, including video and audio recording, field notes, and professor interviews, saved in an organized database by backing up all data by saving in two different, secure locations and maintaining consistent naming conventions with all files, and a chain of evidence was maintained by keeping notes about the work (Yin, 2018).

DATA ANALYSIS

The data analysis followed multi-case study procedures laid out by Yin (2018). Each case was analyzed individually using thematic analysis, and then compared across the cases in a cross-case synthesis, based on the theoretical framework described earlier and utilized qualitative content analysis within each case (Creswell & Poth, 2018; Saldaña, 2010). Specifically, in each case, we looked for all examples of when the instructor used different types of scaffolding, described in the theoretical framework. Each case was first analyzed individually. For each case, the primary researcher "play[ed] with the data," "searching for patterns, insights, and concepts that seem promising" (Yin, 2018, p. 167). The analysis was done over a period of time. First, during the initial classroom observations, the researcher kept notes about key aspects of each professor's talk. These key aspects were briefly discussed by the researcher and the professor after each class period to confirm the professor's intention to focus on these aspects. Next, all the video recordings were transcribed. During the transcription process, the primary researcher continued to make notes and comments about common themes in each professor's talk. All of this information together was used to write the description of each case. The descriptions of each case focused on how the instructor used scaffolding and worked to provide a description of the instructor's scaffolding strategies primarily through examples from the transcripts. Finally, a cross case synthesis was written comparing and contrasting the salient aspects of each case. The cross-case synthesis focused specifically on the different components and types of scaffolding that are described in the theoretical framework. Throughout this process, member checking (Creswell & Poth, 2018) was used to ensure accurate representation of each professor's ideas and actions. Member checking was done through conversations with each professor after each class period, conversations with each professor throughout and after the data collection period and sharing the written drafts with each professor.

TRUSTWORTHINESS

Each of the four principles of high-quality analysis described by Yin (2018) were used to ensure a high-quality, trustworthy analysis. The analysis *attended to all the evidence* by including all the professor's talk from the entirety of the time that students were working on their design projects and all the information from the interviews with the professors. Second, the analysis investigated *plausible rival interpretations* through conversations with the professors and between the researchers. Next, the analysis focused on *the most significant aspects* of the professors' talk, focusing on the aspects of their talk related to the theoretical framework in order to focus on how the professors used scaffolding, rather than on the many other aspects of pedagogy they used in their classrooms. Next, the researchers "demonstrate a familiarity with the prevailing thinking and discourse about the case study topic" (Yin, 2018, p. 199) through extensive literature review prior to the data collection and throughout the data analysis process.

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DESCRIPTIONS OF EACH CASE

This section describes each case, Professor Davis, Professor Pfeiffer, and Professor Wilson, utilizing examples from their teaching and interviews.

CASE 1: PROFESSOR DAVIS

Professor Davis teaches the first-year introductory mechanical engineering course. He is a storyteller who used a range of examples to set up a structure for his class. He views an important aspect of his role as an introductory engineering professor is to help students develop passions for mechanical engineering and expose them to future supports and experiences in their education. Details about how he used his support in these ways are explained in this section.

Used storytelling to build the scaffolding

Professor Davis is a storyteller. When he uses his talk to convey ideas, answer students' questions, or emphasize a point, he does so with a story. As he put it:

> I just, and this is part of just who I am and the way I interact with everybody, but I just like to talk to people and talk about my life experiences and hear their life experiences and just get to know people as people.

This attitude has allowed him to develop and use different stories from a vast range of engineering and teaching contexts that he draws on in his teaching. This philosophy plays into much of his teaching, including the casual manner that he comports himself, or as he said in his pre-interview, "I tend to be very casual. I don't have much of a, 'I'm the professor and you're the student' [attitude]."

Professor Davis used stories throughout the design project. These stories framed many of his interactions with his students and often built on each other to convey ideas through examples, rather than direct instruction. Professor Davis wanted his students to learn about improving their abilities to work in teams and to value different kinds of skills in their teammates. Instead of just telling his students this goal, on the first day of the design project he told several stories to the whole class, including the following story from a senior design team he had work with that included a student who was especially good at supporting his teammates:

> I would watch this group working for the whole year. They had the most fun. They did an excellent job. Everything was on time. The project was great, and I'd watch them together, and you could see him checking in with everybody. Sometimes verbally, sometimes not verbally. Just, "How you doing?", "Is everything going OK?", "Is your assignment going well?" He was the one that was kind of dealing with all his teammates for a year. Just making sure that everybody was happy. These are the kinds of things you, you think if you see someone like kind of fading out of your project and well "we asked them to do this and they didn't do it." It's up to the whole group, right, to say, "come on, you really need to pitch in."

The story shared by Professor Davis is one example on how the instructors used their talk, and specifically storytelling, to introduce through their talk design concepts such as teamwork. Stories like these also reinforce Professor Davis's point that he made several times that teams need a variety of skills and that technical knowledge is not the only thing a team needs to be successful. Later, on the last day that the students were working on the design project, a student came up to Professor Davis and said, "so one of our team members hasn't shown up and has not been helping out at all. [...] He's been present. He just hasn't helped. We have a group chat, and he hasn't replied at all." After asking who the student was and checking that they had turned in other assignments to check if they were still in engaged in the rest of the class, he responded with several stories:

> Professor Davis: My niece was homeschooled, all through high school, and she started college last year, this is her sophomore year. And right away, the first thing she was talking to her parents about was the

	group stuff. She's not used to it, and she doesn't like it. You know because she's just like, people don't show up and people don't... She's very responsible and it's always tough from the instructor's standpoint because, you know we have team based senior project now, that started 15 years ago, but it came from industry, that's what they want.
Student:	My high school's actually really project-based learning.
Professor Davis:	So, you've done a lot of it already. But it is something we spend, you know, we do think about. And you'll always, you know, a lot of your labs are going to be team based.

In this example, he used his talk to validate the difficulties of working with a team, but pointed out that it was a necessary thing for the students to learn to meet the expectations of the industries they were working towards joining, therefore scaffolding their skills of working with teammates. These stories demonstrated a typical scaffolding pattern in Professor Davis's class. He is working to use contingency, by talking to the students about their experiences and working from that. He used stories from his experiences to give examples to the students about how they could think and approach problems. He never directly told them what to do but instead gave them many examples of how they could act and left it up to them to make the final leap in their zone of proximal development and make decisions about what they should do.

Scaffolded students' understandings about mechanical engineering as a discipline

Professor Davis holds the view that one of his primary roles as the teacher of the introductory mechanical engineering course is to help students understand their passions and to identify if mechanical engineering is one of these passions. This view was evidenced, for example, by the following comments he made with a team:

Professor Davis:	To me, it's awesome that we have you guys declare as freshmen because we get to do this [class]. And we get to...I had two students doing a makeup lab last week, they're both switching out of ME.
Student:	Really?
Professor Davis:	Students always think, "Oh, you're going to try to talk me out of it." No, it's one of the reasons we do this.
Student:	It's like a little like trial period, right? To see what it's like.
Professor Davis:	Yeah. So one of them is going into industrial engineering. A lot of high school counselors and things don't know about industrial engineering. It's one that they graduate 130% of the students they bring in all the time, because they're just a net importer, because people don't pick it as freshmen, but it's a great career.

Many of his interactions with students served a purpose to scaffold the students' ideas about mechanical engineering to build on their knowledge of what is possible with mechanical engineering. His strategies of engaging in stories with his students help him both to share his own passion for mechanical engineering with them as well as help them identify their own passions. Many of his conversations with teams of students as they were working on their design projects consisted of just talking about aspects of mechanical engineering that they found interesting. For example, when students were prototyping their ideas with their teams, a team started sharing one of their ideas with Professor Davis, saying:

Student 1:	So basically it's a hand held stick that allows users to mouse again, like a computer mouse. Basically, it has a high friction pad here so when you press down the mouse and you move alongside with it. No problem. And the way you click the buttons is very simple, you just twist your forearm. You just pivot off of this.
Professor Davis:	[mimics hand twisting] So, click, click, so right and left would be…
Student 1:	Yeah.
Professor Davis:	Have you ever seen a foot mouse?
Student 2:	Wow, there's such a thing?
Professor Davis:	Oh, yeah, yeah. They have them now, it's tough, right?
Student 2:	That sounds so impractical.
Professor Davis:	You know, if you don't have a hand. Actually, a lot of people get carpal tunnel problems from too much mouse use and so it's not that they don't have a hand.
Student 3:	Have you seen those mouses where it's like a slide thing, and you go up. Like basically it's a tube and there's an outer thing [gestures with hand to describe shape] [Students and professor continue talking about different types of computer mouses.]

In this example and others like it, Professor Davis encouraged the students to think about different applications of the designs, different potential users of the designs, and shared applications of mechanical engineering that he had seen benefit different people. These examples demonstrate how Professor Davis encouraged his students to think about different aspects of mechanical engineering and how these "cool" things could help people with a variety of needs. Professor Davis used conversations like these as a form of contingent scaffolding to take students' ideas and push them to think about things such as other aspects of the problem, other design criteria, or other potential solutions. In these examples, he modeled different ways to expand on the problem and potential solutions, using language that acted as a scaffold to students being able to think about different potential solutions to a problem themselves.

There is evidence in the students' conversations that they were listening and taking these ideas to heart. The following series of examples show one example of this evidence using quotes from both Professor Davis's and Professor Pfeiffer's classes. At one point when a team was prototyping, one of the students was wearing one of their prototypes for their idea to design glasses with visual inputs for hearing impaired users while they are skiing, Professor Davis said to this team:

Professor Davis:	That is a cool idea with the [refers with gestures to glasses prototype student is wearing] to kind of let you know what's coming from behind.
Student 1:	Like flashes [of light] on the sides.
Student 2:	And it's like proximity so the light dims, depending.
Professor Davis:	It's one of those you kind of go, maybe everybody wouldn't mind having one? You've never cut someone off coming from behind you? [sarcastically].
Student 3:	Skiing? Never [sarcastically].
Professor Davis:	Never happens? [laughs]

Student 3:	Especially listening to music when I ski. The snowboarders, no offense, are the absolute worst about cutting people off because, it's like nothing about you, it's just literally how snowboards are built when you turn, you can't see anything behind you. So that's why skiers hate snowboarders cause you just like cut us off.

Later, during the last day the students were working on their project in the seminar class, the same team as in previous example had the following conversation with the other professor in the room, Professor Pfeiffer:

Professor Pfeiffer:	What project are you doing?
Student 1:	We're doing for deaf people, ski goggles that have sensors, so it alerts them to things like objects and obstacles.
Professor Pfeiffer:	Oh, that's cool.
Student 2:	It's kind of like with the car, how you have a blind spot monitoring. It's like that.
Professor Pfeiffer:	Yep. Oh, that's nice. Yeah.
Student 1:	And I feel like that would be useful for even like … I would use that when say it's hard to hear. So we were thinking, sensors that just like measure relative speed, and alert you if someone's going to like pass you.

This example shows that during the first interaction with Professor Davis, the students were listening to his comments about the idea being useful for other user groups. The scaffolding that Professor Davis had provided, in the form of pushing them to think about other potential users of the design, was effective enough that they took his ideas enough to heart that they repeated it to their other professor several weeks later.

Explicitly discussed future support and scaffolding

Professor Davis made frequent references to their future experiences at the university and in their careers, relating what they were doing in their current class to future opportunities. For example, during his introduction of the project to the whole class, Professor Davis said "I told you guys from the beginning, this is like a mini shot at senior project, right? This is, we're doing the same thing we do in the beginning of senior project." Here, he explicitly told the students that they were practicing a design process for their future, in this case for senior design. A few minutes later, when explaining to the whole class what they will be doing for the design project, he told the class that they would be prototyping their ideas with simple materials and described how they would use more advanced materials later in their academic careers as they learned more about design:

> This is foam board and glue sticks and, and we've just, we want you to get down to three ideas today. That's the goal is to have a team and have three potential ideas. […] Has anyone ever heard of the company IDEO, IDEO? It's out of the Bay area. Kind of spun off of Stanford, bunch of Stanford people. This is one of the things that they say all the time is just build it, build it, build it. You know on Tuesday, it was really neat [in the prototyping lab where the class was working and two senior design project teams were also working]. […] There was a third quarter senior project team building [their final project prototype with] stainless steel axles and big metal parts, and there was a first quarter senior project team doing a PVC prototype, first full-scale prototype of what they're going to build in the spring. And then all the freshmen working with me kind of surrounding them [working on their prototypes with simpler materials]. So, it's kind of cool to see that we're just going to keep encouraging you to do this [building with more and more advanced materials as you prototype more].

In this example, Professor Davis referenced a design company and their philosophy about prototyping, reinforcing the idea that the students are practicing the same techniques as engineering designers in industry. He then expanded on other experiences the students would have at the university that would help them develop these skills further. In doing so, he explicitly told the students about the scaffolding and supports that were in place throughout their experiences at the university. Here, he was describing to them the transfer of responsibility that would help scaffold their learning throughout their college experience. He laid out to them that in this introductory class, they would have the support of him as the instructor, but eventually this support would be taken away and they would be expected to work more independently on their projects.

Scaffolded engineering content knowledge

Professor Davis used conversations with the teams to introduce or expand on engineering concepts that they will learn about later in their education. In general, he presented the project as a chance to practice design skills, such as problem scoping, brainstorming, teaming, and the like. Although he set up the classroom to support the students through the engineering design process, there were few instances in which he directly talked about the design process or how students should move through their design process. One example in which he did directly give support to the students about how to develop their solution occurred during the first day of the design project when students were developing their prototypes:

Student:	So, if we already know which thing [design idea] we're going to do specifically…
Professor Davis:	[interrupting student] No you don't.
Student:	Do you want us to make three still?
Professor Davis:	You don't have to make three prototypes, but I want you thinking about three ideas. So you want… how would you make it, what kind of materials? So you want to, you got enough time today to kind of think about three and basically you still have tomorrow to narrow down to one. And then you'll really start detailing it out and try to do as much as you can.

In this example, Professor Davis told the students that they should still be considering multiple ideas, providing some support to prevent the students from becoming fixated on a single idea early in the design process. By requiring students to develop three ideas, he is using designed-in scaffolding to help students overcome idea fixation.

Other times, Professor Davis provided scaffolding for the technical engineering science content, although this content was also rare. He did not expect students to apply complex engineering ideas yet in this introductory project. He clarified this expectation to one team by saying, "Look, you guys, we understand, you haven't had materials science yet. You just, you're going to do more, describe 'I want it soft, but not too soft'." However, when he noticed misconceptions that the students had, he told them further information about the concepts to help overcome these misconceptions before they were further reinforced. For example, earlier this same team wanted to use a gel like material to hold an attachment in place. Professor Davis took some time to explain the properties of the material:

Professor Davis:	But I think the jelly, it, it creeps we call it. So, if you put a load on it, it'll never stop moving. It'll just keep going like this [demonstrates with hand].
Student:	Got you.

Professor Davis: There's plenty of things that will work. Just say like an elastomer, some kind of elastic. But the jelly is, even plastics, all plastics do that [picks up piece of plastic from table]. If you put a high enough load on this, if you left this here overnight and come in tomorrow the displacement will be higher tomorrow than it was today.

Student: Yeah?

Professor Davis: Plastics creep. If the load was low enough, the creep would be so small you wouldn't even be able to measure it, but if you put a high enough load on this, and you know we set it up in a ring and measure the displacement, when we come back tomorrow, it will have gone further. [continues with explanation about how they will learn more about this in future courses]

In this example, Professor Davis gave the students some information about the topic, while also reminding them that they had a lot more to learn about the topic. This situation required Professor Davis to assess the students' understanding of materials, identify that they had a misconception, and judge how much information to give them to overcome this misconception without taking too far of a tangent from what they were currently working on, demonstrating many of the challenging aspects of effective contingent scaffolding.

Professor Davis used storytelling throughout many of his interactions with his students to build a framework for the students to think within. He used his stories to give students examples of how to think about problems and to provide scaffolding for furthering their ideas. He used his talk and interactions with his students to build on their passions for engineering and to help them understand the discipline of mechanical engineering. He also explicitly discussed their future careers at the university and in industry and connected what they were learning in their introductory course to these future experiences. Professor Davis scaffolded technical content about engineering design if he noticed misconceptions, but usually focused their attention on learning about other things outside of pure technical knowledge, such as teaming and iteration of designs.

CASE 2: PROFESSOR PFEIFFER

Professor Pfeiffer also teaches the first-year introductory mechanical engineering course. He used his talk to set up a structured classroom environment. Within this rigid structure, he encouraged students to explore broad design ideas independently. During his interactions with students, he primarily listened, interjecting with pointed questions only to push students' ideas further and to remind them of specific components. The following section describes his case with examples from his teacher and interviews.

Used a structured class environment to build the scaffolding

Professor Pfeiffer uses his talk to set up a very defined structure for his class that students could work within to explore their design ideas. This structure fit well with his personality and his views about teacher-student relationships. His view is evidenced by a comment he made in his pre-interview:

> I think, from my experience, there needs to be a tradeoff between being formal and being a friend overall. And so there is, there is I think a good level there where if you are too frank, for example. But that's, that's me personally, and I'm coming from Germany, right? Where we have more formal, I don't let students call me by my first name, whereas I know some other colleagues do, and it might fit their personality better. But my, my thing is I stay as Professor Pfeiffer, but I am available even for personal problems if you want to talk to me, and I help you out. I think so the right balance because

> otherwise I think students confused, "Oh, he's my friend. I don't need to put in the effort. He gives me A anyway." No. You get evaluated based on did you achieve the learning objectives, yes or no? And this is not on the personal relationship you have with me.

His desire to maintain a structured class played out in his teaching. For example, the activity he designed to help students choose their teams was very structured. On the first day of the design project, students came into class with a completed homework assignment that contained at least four potential ideas for a design project. Professor Pfeiffer wanted the students to be able to share their ideas with many other students in the class and use these interactions to choose their teammates. To do this sharing, he divided the class into six groups and had each person from one of the groups sit at a different table. He then said to the whole class:

> Everybody gets their own table. OK, so this is how, this is how we will be doing that. It's called "find your design project speed dating." OK, you will have one minute for your elevator pitch. [...] Three person per table go to whatever table you want to start so we will rotate in this manner.

While this activity was going on, he stuck to a rigid timetable and required the students to move onto the next group at the end of each minute. He structured this activity in a very controlled manner that still allowed students to get a lot of practice explaining their design ideas and learning about other design ideas. This is an example of designed-in scaffolding that provides students with a planned structure to practice these skills.

One of the structures that Professor Pfeiffer used was to reference the engineering design process. He did not use many detailed explanations of the design process, but when interacting with teams of students, he often referenced it as a structure to form their ideas around. For example, Professor Pfeiffer had the following conversation with a team of students who were working on an idea to make a credit card shaped device that a person who is colorblind could use to identify colors:

Student:	Is there a particular point that you would like us to get to? An end goal?
Professor Pfeiffer:	Well, remember the end goal is you have your final prototype and to have your poster done.
Student:	So, work until we get to there?
Professor Pfeiffer:	Correct. Improve and then think about what else can you do. It doesn't mean you have to stick with that one idea. So, if that does identify color, maybe you can expand it, you know? Can think about: Are there other constraints? Using that, is that really comfortable in my hand? If it's a box like that, do you want to have it more ergonomically shaped? So like I said, you have plenty of time to think, work about it, use the engineering design process, right? This is actually hands on doing it, kind of learning about it, learning about iteration, learning about the requirements, how do you evaluate that design. If you want to go further if you have more time, how would you market the device?
Student:	Sounds good.
Professor Pfeiffer:	Again, the sky is the limit.

In this example and similar ones that occurred frequently, Professor Pfeiffer reminded the students about the engineering design process, especially the iterative nature of the design process, and related it to the particular point they were at in their project. However, although he made short references like these to the engineering design process or two particular aspects of engineering design, such as the importance of iteration, he did not define or support a defined structure to the engineering design process.

Supported independent exploration of ideas

Professor Pfeiffer believes that students should have the freedom to try out ideas and explore engineering design within the structured classroom environment that he set up. He shared this view that they should be exploring their ideas directly with the students several times. For example, he had the following exchange with a student during prototyping on the first day of the design project:

Student:	Are we allowed to attach flame throwers to it?
Professor Pfeiffer:	You can, yeah, whatever, it's completely up to you. Again, think outside the box, right? I mean, come up with crazy ideas and then evaluate and see what's possible, right? So, this is usually how that works. Brainstorming phase, nothing's off the table.

By using his talk as design-in scaffolding to give a solid structure of the class, he allowed students to be able to focus on their ideas and come up with crazy ideas, rather than worry about what they need to do to do well in the class.

Although he was very hands-off in his approach, allowing students to explore their ideas themselves, Professor Pfeiffer often checked in with the teams to hear about their design ideas and answer any questions they had. During these interactions, he primarily listened. If he determined that the team was on track, he would leave without saying anything or interrupting. If he noticed that they needed extra support, he would interject with short questions, as demonstrated in the following example. Professor Pfeiffer stood near the team throughout the following dialogue, listening to their conversation for several minutes before making the short comment in the example. This team was working on an idea to make a swing that would be easier for a child with a disability to operate and were discussing possible ways to attach the rope to the swing.

Student 1:	I have an idea. If you put a second rope connected to the handles, from the swing to the handles, then at every point the handle would be close enough that if you dropped it would still be easily droppable from the swing.
Student 3:	So are you saying like a mini string right here that holds it like that?
Student 1:	Yeah
Student 3:	So as it goes, it goes like that.
Student 1:	It would go with the swing. Because that would have
Student 3:	So then if they dropped it, they'd just have to pull on that little string.
Student 1:	Exactly.
Student 2:	What if we could make use of some crazy knot where we could like, in a small amount of space keep a large amount of rope, but then as you move it would just draw rope from that, you know what I mean?
Student 1:	So we have like a tension system?
Student 2:	So because if you're only using like, if you need a short amount of rope but you still need the full range of motion of the swing, maybe you want to have some way of like keeping a large amount of rope in, you know what I mean?
Student 1:	Yeah.

Student 2: Cause like if you're using a short rope your swing's not going to move.

Student 3: Would you like to create that knot? [...]

Student 2: Isn't that, can't you do that? I'm not crazy, that's got to be a thing.

Student 4: I don't think that's a thing, that's just like an infinity knot.

Student 3: I love infinity knots, but they're really difficult when you're trying to swing.

Student 1: I don't know about a knot, but you could make a coil that was like spring loaded so that it would constantly pull on the one end. [...]

Professor Pfeiffer: So keep in mind right, if there's friction, it will slow down the swing.

Student 2: Right.

Student 4: That's what we're doing, these are like little friction holders [points to prototype]

Student 3: That's so they can pull on the rope.

[...Students argue over who can tie the knot...]

Student 1: I am not the knot guy. There could be a knot out there, but I wouldn't know about it.

Professor Pfeiffer: Well, you can go and google it, right?

In this example, Professor Pfeiffer primarily listened while the students hashed out their ideas. He made two small interjections, to point out something else they needed to consider, friction, without telling them directly how to address it, and to give them an option to find out a solution to the argument they were having, to do some research. This type of interaction was very common in Professor Pfeiffer's class and gave him opportunities to use contingent scaffolding to assess where his students were and give support directly to the team if needed.

Although he did not give much direct input to teams as he was listening, he was very diligent about remembering what they were working on, what they were going to try next, and revisiting these ideas with the students. The following series of two examples demonstrate this pattern. A team was designing a device to make it easier for a user with a single arm amputation to drain pasta. At one point, the team was discussing how to clamp their device to the counter and was unsure about how large their device would be and were concerned about the weight. Part of their conversation was:

Student: We were also thinking about just a stand. With like a heavy base. But that'd be a lot of weight. I don't know a way to circumvent that.

Professor Pfeiffer: So yeah, I see you have lots of ideas to build multiple prototypes to say, this is for clamping, this is for base, you know. And then you need to think about the weight, how much should it carry, right? Are we talking a pound or if you're filling a gallon, you know?

Student: I'd say at least, yeah. A gallon, how much is a gallon? 5 pounds?

Student: Is 5 pounds good, or heavier? Ten pounds max?

Professor Pfeiffer: Well, you're designing it, right?

Student: I'm going to say 10 pounds.

Professor Pfeiffer:	10 pounds?
Student:	Ten pounds is big.
Professor Pfeiffer:	Yes.
Student:	[to teammate] Research how much a typical serving size of pasta is.
Student:	Actually, I'll be right back. I'm going to go fill this [cup they are using in their prototype] with water and see how much that weighs.

During this interaction, Professor Pfeiffer did not directly give the students any ideas. When they asked him a question, he either restated what they had already said or pointed out that they were the designers, not him, leaving the design in the students' hands and maintaining their control of their ideas. Thirteen minutes later, Professor Pfeiffer returned to the team and said:

Professor Pfeiffer:	So how did it work out with the water?
Student:	We didn't get to exactly balance it.
Student:	It wasn't really the weight that was the problem, it was flipping side to side.
Professor Pfeiffer:	So, it was not stable basically?
Student:	Yes.
Professor Pfeiffer:	Ah, OK.
Student:	I guess we're going to, I guess in our final design we're going to design something to lock it.
Professor Pfeiffer:	Yeah, that's a good idea, yeah. See by experimenting around, you get more ideas to improve it.

His process of checking on the students held them accountable for improving their designs and following through on their ideas, without him needing to interfere directly in their design processes. This process allowed the students to maintain their control of the design but kept high expectations of what they should accomplish. Additionally, it gave them several opportunities to ask questions if they needed support from the instructor as the more knowledgeable other. This is an example of transferring the responsibility to students.

Adapted his talk to meet the students' needs based on frequent questions to the students

Professor Pfeiffer highly values personalized interactions with his students and adapting his pedagogies to fit their needs. This value was evidenced in his pre-interview when he responded to the question, "What do you think are effective ways that you as a professor can support your students when they struggle during design projects?" saying:

> [...] it's regularly meeting with them in person. So we do that in the HVAC senior design and yeah, you need to put in the time and effort as well. So it really depends on the project, on the students. From my experiences you cannot just say "okay we meet each week for an hour" because for some, at the beginning, I just need to meet with them 10 minutes and then later, for example, I need to put in three, four hours with the students. And that, you know, it varies. So you need to be able to adjust to that. You cannot like can it and say, "it's always an hour and that has to be enough." If you really are interested in helping the students succeed.

Throughout the design project, Professor Pfeiffer used contingent scaffolding to frequently check in on the students, ask them to share their ideas and base the rest of his interaction on his assessments of their progress. He did not directly tell them any ideas or suggest specific ways for them to move forward. He used prompts and questions to challenge their ideas or provide next steps. As an example, he had the following conversation with a team after they had formed a team and started brainstorming their ideas:

Professor Pfeiffer:	So, what is your idea? Or ideas you want to pursue right now?
Student:	One of the ones that we singled out is a wheelchair mount on a longboard.
Professor Pfeiffer:	Oh, OK.
Student:	So it would allow users to like roll up onto the board then it would lock into place.
Professor Pfeiffer:	Mm-hmm
Student:	And it'd be electric, so they control like acceleration and braking.
Professor Pfeiffer:	OK.
Student:	And then there'd be like quick release buttons on the side to unlock and pull it off.
Professor Pfeiffer:	OK, cool. Yeah well you have the stuff here [to prototype with], right? You can cut the cork, you have little wheels, toothpicks whatever, yeah.
Student:	Absolutely.
Professor Pfeiffer:	OK, good.

In this example, Professor Pfeiffer gave his students opportunities to practice explaining their ideas, thus moving towards fading of the scaffolding. He let them know that he was available if they had questions and confirmed that they knew what materials they had available to them but let them continue with their design ideas however they chose.

On the other hand, when Professor Pfeiffer made assessments of the students and determined that they needed more support, he prompted them with questions or further things to consider. For example, while a team was finishing up a prototype, he complimented their work and then suggested:

> So the idea is to come up with a prototype, right? And then evaluate. That's what engineers do. So let's look what we can up, pro and cons, right? Write them down and then think about to improve it, OK? That's the iterative process of your design. Did you address all the customer needs? Yes or no, right? Is it safe? What can be done better? What are some of the challenges we perceive, right? If you keep your first prototype and then you build a second one later you can show the progression, right? How you started, this was the first idea but then that was our final idea, and these are the reasons why that final one is better than that first one we did.

In this example, the students had already built one prototype. Professor Pfeiffer provided scaffolding by asking questions to help them think about how to push their ideas further. He did not give direct advice about their prototype or idea but did remind them of things they should be considering and how these considerations fell within the larger scope of the project and engineering. Professor Pfeiffer made very similar comments to this example to all the teams, but at different times based on their progress.

Professor Pfeiffer used his talk to scaffold his students' learning about engineering design in a variety of ways. He used his talk to set up a very structured environment that allowed students to clearly understand what they should be doing when. However, within this structure, he gave his students freedom to explore their ideas and push the limits of their knowledge. He supported this exploration by frequently checking on the students and using his interactions to assess the students' understandings in order to tailor his scaffolding to what each team needed in the moment. During interactions with the students, he did not give direct answers, instead prompting them by repeating their own comments in different ways, asking questions to further their thinking, and prompting them to think about other aspects of the problem.

CASE 3: PROFESSOR WILSON

Professor Wilson teaches the sophomore level biomedical engineering course that includes the students' first experience with design at the university. He used his talk to provide students with a scaffolded industry practice. He views his role as the introductory professor is to prepare his students directly for their first internship or industry experience, especially with the acronyms and language about biomedical engineering processes that they will need to understand their industry colleagues. The following section describes how these patterns were illustrated in his classroom and interviews.

Structured his class as a scaffolded industry practice

Professor Wilson held the viewpoint that his course should directly prepare his students for an industry experience. He used his talk to set up a classroom model similar to what he has seen in industry. For example, he said to the researcher:

> When I took it [teaching of the course], all I did was I said, "I'm just going to treat this class like I would treat my company or what I would do in industry," and literally, that's just what I did. I just started treating the students, I said, "I'm going to make this feel like you're project engineers."

This philosophy is mirrored in how he set up his classroom and how he talked to his students. Overall, he spent some time giving an introduction to the project and telling students the important parts of what they needed to do. He did give the students several guiding prompts but left the project very open-ended, evidenced, for example, when he told the whole class:

> You will have an aim … something rough that describes the problem. And then you'll talk about, what will be the deliverable, maybe it's a process, maybe it's a product, maybe it's a service and a process, and you're going to roughly talk about what you think that's going to be. … And then what do you think the impact of your device will have in that market space? What will be the impact? Will it be something that help… you know I talk about what my company's working on, will it be something that will help move people that are asymptotic in cardiovascular disease into the symptomatic range [like my company's product does]? … What you want your product to do in whatever space you are interested in as a team.

After giving this information, he let the students work. He answered questions when students came up to him but did not check on teams or interrupt their work. As he said in his pre-interview, "I like for them to be able to solve it themselves. If they can't, then I will get involved." This demonstrates his contingent scaffolding, adapting as needed. There were only three instances in which teams asked questions to Professor Wilson. One of these examples, was the following conversation:

> Student: I just wanted to like get your sort of like opinion on like the scope of these ideas. The first one is like a targeted chemotherapy. Because chemotherapy kills a majority of the cells. So this would be like marking the cancer cells and then targeting those specifically. The second one would be targeted treatment of

	bacterial [pause], with antibiotics that could mutate at the same rate as the bacteria. The last one would be an early diagnosis and cure for Huntington's disease.
Professor Wilson:	I think those are good.
Student:	Those are pretty, Where it's more, some of them are more like conceptual.
Professor Wilson:	Like diagnostics, it's like diagnostics, but you'll talk about how you're going to diagnosis it.
Student:	Right. So these are good scopes?
Professor Wilson:	Yeah, yeah. That's fine

In this example, Professor Wilson listened to the student and gave some validation for the ideas but did not critique them at all or direct the students how to proceed further.

He expected students to do most of the work for the project outside of class. Other than the 50 minutes during the initial class period, the students completed the entirety of the project outside of class time.

Modeled specific language and acronym use

Professor Wilson based the goals of his class and the ways that he used language in his classroom on his experiences in industry. He wants his students to be able to go out into the biomedical engineering workforce and be prepared for success. This goal was demonstrated, for example, when he told the researcher about his experience as a college intern being shocked that he had something to contribute. He said, "I don't want them [the students] to go into a company and be shocked that they have something to contribute."

Professor Wilson views a significant role of his talk in the introductory class is to prepare the students to be familiar with the language of the discipline of biomedical engineering so that when they go into internships and other industry experiences, they will have the tools to be able to communicate with their colleagues. He stated this aim in his interview with the researcher when asked about important aspects of language in the classroom, "My job is to be kind of the intro person that makes these biomedical engineering acronyms begin to become second nature." He uses acronyms frequently with his students and is up front with them about his goals to help them learn the acronyms, and he agrees that there are a lot of acronyms in engineering that they need to learn. In the following example, he brings up several acronyms when talking to the whole class:

Professor Wilson:	The high risk is class 3. And there's a different pathway for that. But remember there were two different pathways. We had generally exempt, we had generally this pathway and we had this key word, do you remember this key word? [writes word on whiteboard] We had that key word that was in there.
Student:	510K
Professor Wilson:	510K, that's exactly right. And then we had, you know we've gone 5 minutes in the class without an acronym, so we have to have one, right? [laughs] So class 3, is what?
Student:	PMA
Professor Wilson:	PMA. OK. Pre-market approval.

In this example, Professor Wilson expected the students to come up with the acronyms for the situation, continuing a standing joke that they do not go five minutes in the class without using an acronym. This is an example of him starting to use fading in his scaffolding, by decreasing the level and support and expecting the students to use the acronyms.

In addition to the use of acronyms, one of Professor Wilson's major points of emphasis was on the procedures that an engineer needs to go through to produce their project and support the students to be able to use the language associated with those processes. For example, when he introduced the project, he used an example project [called House Calls Mobiles] from a previous student to walk through some of these steps and processes:

Professor Wilson: She had a very novel idea. And hopefully, it's useful and not obvious, right? Because then...

Student: Patent.

Professor Wilson: She can get a patent … And she actually has, she did get a patent, so it did meet those three criteria. And what it is, it allows a physician to do remotely, to have the ability to hear heart sounds and to actually do an inner ear examination at the same time, so it's a combination otoscope/stethoscope. And it's virtual. So this was a team that worked on it. Some of the students are gone. Some students are here [at the university]. [pulls up slide for "Indications for Use"] Why is this important? We talked about this. What is this? Why does the House Calls Mobiles need this?

Student: You need to say to the FDA what your device does and who you tested it on and then how, which age, which type of people would it benefit, you could use it for.

Professor Wilson: Yeah. This is her contract with the FDA. It's stating what the product does. Who it's going to be used on. What its requirements need to be. Maybe where it can't be used and it has all this information here. So, this is her indications of use statement. So that's the first thing the team developed for her. [continues talking about FDA requirements]

This example demonstrates an example of the ways that Professor Wilson emphasized the language around the processes of biomedical engineering. He recalled prior knowledge about the language used around patent processes and expanded on this idea to further explain what needs to be done through the process. He posed many questions that students should be thinking about as they develop their design and the documentation around their design.

Supported opportunities to brainstorm "unfeasible" ideas

Professor Wilson views a purpose of the introductory design class as helping students brainstorm ideas about the potential future, even if these ideas are not feasible yet. At the very beginning of his introduction to the project, he told the whole class:

> I don't necessarily want you to think about things that…they don't necessarily have to be feasible. At this point, because you're not going to have to build them, however, what I want you to be able to do it still go through the steps as if they were feasible and be able to develop these stages for the concept review because at one point basically anything that you see that's on the market right now there was a point when people said it was probably impossible to make. Right? Right? And so, I don't want you to keep yourself in the box up saying, "OK, it's got to be, you know, similar to the current digital measurements that are made for temperature or whatever." I want you to think outside the box because at some point, maybe there will be the technology to do the things that you're going to do, and you will already have it at a concept review, you'll be able to move forward. So that's really the game plan.

In this example, Professor Wilson encouraged his students to brainstorm broadly and to consider unfeasible ideas. He pointed to the rapidly changing nature of working on design projects and the need to be forward thinking in order to develop successful designs. Here, he is using designed-in scaffolding by giving students explicit tasks that are planned to develop their skills and knowledge.

In addition to promoting students to brainstorm unfeasible ideas, Professor Wilson encouraged the students to develop their ideas further and often reminded them of the entrepreneurial potential of their ideas. He said similar things several times in his talk to the whole class, such as with references to the example design project he was using and references to his own company (in earlier examples in this section). Additionally, although he only had a few interactions with teams of students, he continued his support during these interactions. For example, Professor Wilson had the following conversation with a team as they were working. The team approached Professor Wilson with an idea involving glue to keep tissues together they were interested in:

Professor Wilson: I think that's a good idea. The thing that's really good about these is hopefully you'll keep them and you'll keep these ideas when you take [other class names]. Because one of the things I'm working with right now, I'm working with real sponsors that are outside and I think I told you that one of the sponsors is back in [place name] and we're developing a novel in vitro feralization tool with some graduate students and so there's positions that we can get to help and I think the beauty of kind of what you saw with senior design [points to slides] and these ideas is they're not academic projects. They're real projects. It's good and it's bad because there's some pressure, it's not just a class now. You know, so it's good and it's bad that they become real.

Student: There's consequences.

Professor Wilson: Yeah, I think it's good and it's bad, but for the most part there's more good than bad that comes from it.

In this example, Professor Wilson validated their idea and pointed them in the direction of a specific person that he thought could give them more support to develop their ideas. He encouraged them to think about the real-life applications and potential of their ideas.

Professor Wilson used his talk to set up a structure similar to his experiences in industry in which he gave students initial, open-ended instructions and let them work mostly independently. He emphasized specific language used in the biomedical engineering industry, especially acronyms and language around regulatory processes. He supported students' brainstorming of unfeasible ideas and pointed them in directions to further develop their ideas and apply those ideas to the real world.

CROSS-CASE SYNTHESIS AND DISCUSSION

This section synthesizes across the three cases based on the theoretical framework. The patterns that emerged are based on the results of each case and supporting data from the interviews are used to add additional support to these patterns.

OVERALL APPROACHES TO USING TALK AS SCAFFOLDING

Each of the professors had different approaches to how they used their talk to scaffold their students during engineering design projects. For example, although they all set up the project as a team project, when students were actively working on their projects in teams, each professor had a different approach. Professor Pfeiffer's primary strategy was to approach teams, ask students to explain their ideas, listen to their ideas, and ask a few prompting questions. He assessed each team's progress and tailored his prompting questions to where they were in the process to push their thinking forward. His interactions with the students were on topic and did not last any longer than they needed to in order to assess the team and make sure they were on a good track. Professor Davis, on the other hand, had longer interactions that usually involved stories and talked about other "cool" ideas related to their design. He often went on tangents with the students to talk about a host of topics, some closely related, and others not related to the project the students were working on. Professor Wilson took a still different approach and rarely interacted with students as they were working, except in the rare case when students initiated a conversation, in which he followed through with suggestions of how to move forward. Each of these approaches demonstrates a different approach to using talk as scaffolding. Professor Pfeiffer used his talk to scaffold student in a pattern, asking for student ideas, assessing those ideas, following up with prompting questions, checking on students' progress, and repeating, that is very common and has been shown to be effective (van de Pol et al., 2014). Professor Davis was much more casual in his support, often intertwining the support within a story in a less clear manner, but still giving the students support and interacting with them for longer periods of time. These interactions had the advantage of providing students with context around what they were working on and helping them develop relationships with their professor. Additionally, his strategy of using stories to situate design learning agrees with the work of Lloyd (1998) that found that storytelling is a way that designers explain their experiences and incorporating the social nature of design. Additionally, Professor Davis's support more often reached further than the small design project the students were working on to incorporate scaffolding about their larger career and academic goals and to provide a cognitive apprenticeship experience for the students (Collins et al., 1989). Professor Wilson's approach allowed students to practice working independently, which is what he valued from his industry experience.

ROLE AS A MORE KNOWLEDGEABLE OTHER

Each of the professors acted as the more knowledge other in their classroom; however, they used different methods to establish themselves as the more knowledgeable other. Professor Wilson was very explicit in that his experience in industry supported his role as the more knowledgeable other. He used phrases referring to his personal experience, such as "I went to my first internship," "that was my experience when I started designing guidewires," and "what my company's working on." In his interactions with his students and his comments during the interview, he made it clear that his time in industry gave him experience that he wanted to share with his students and that most of his examples and perspective came from his personal experiences. Professor Davis relied on his experiences with a wide range of contexts and through interactions with diverse groups of people. For example, he often told stories based on the experiences of his friends and others he had interacted with. A few of the people he referenced in his stories when he was talking to his students were, "my wife is an occupational therapist, which is kind of like a physical therapist and she does rehabilitation," "I was at a wedding quite a long time ago. Two managers from Intel getting married," "my wife's best friend's son, from back east," "I had a guy that I did my PhD with who was actually a Swiss guy," and "We got to this dive resort in Indonesia [...] we're having dinner with a guy that got nine stiches behind his ear from a triggerfish the day before." These examples demonstrate the diverse groups of people that Professor Davis interacts with to gain the experience that has made him the more knowledgeable other in the classroom and how he incorporates their experiences in his talk to provide a rich, diverse experience for his students. Professor Pfeiffer, on the other hand, structured his talk to support students acting as more knowledgeable others for each other, as shown in the examples in his case description. During his interactions with students, he said much less than the other professors, instead pointing the students to support each other and prompting them with questions to discuss in their teams. In each of the cases, the professor was the more knowledgeable other (Vygotsky, 1986), but they emphasized different strengths that they had and different things they were more knowledgeable about. These findings indicate that professors emphasize the aspects of design that they value the most. In Professor Pfeiffer's case this value was in giving the students opportunities for open-ended exploration of their ideas; in Professor Davis's case this value was in integrating the design project with stories that related to life in general; and in Professor Wilson's case, this value was in giving the students practice being an engineer in industry. This finding has implications for what is emphasized in design education.

It shows evidence that each professor took on a different role and that each student's experience was not the same, implying that the professor's values and experience make a difference in how design is portrayed to students.

One of the ways that both Professor Davis and Wilson differentiated themselves as the more knowledgeable other was through their experiences with failure. They both valued the importance of learning from failure. These values are evidenced in their interviews. When asked "What do you think are effective ways that you as the professor can support your students when they struggle during these engineering design projects?" Professor Davis said:

> [On the first day of my junior level class] the second to last slide is [name], who was a famous graduate from here in aerospace engineering. The guy designed and built, God only knows, 50, 60, 70 airplanes and he's the designer of [a famous spacecraft], [dialog cut which may reveal the identity of the institution]. And he came and talked here, and he said, "If my engineers aren't failing three or four times a year, they're just not trying." And so, I talk a little bit about that and then my last slide is Yoda, and it just says, "The best teacher failure is." So, I try to let them know that, especially in a design space that you know, or by definition, we're doing things that haven't been done before and you're going to fail and it's okay.

In response to the same question, Professor Wilson said:

> I always try to let them [the students] know that the struggle is an important part of being an engineer. I share with them my failures as a design person and I try to tell them that failure is a part of success and that's the hardest part, is when you're their age. [...] They're all used to being like Steph Curry at the free throw line making like 95 percent. And I tell every student that it doesn't work like that. You have to think like you're a really good baseball player and if you get 33% you're good, and, and, but it's tough to do that when you're 18 and we get these amazing students that their average GPA is like 4.9 out of four. And so clearly, they've never not got 100% and I think it's hard to go from when you're used to just sitting down and always getting everything right to all of a sudden, "Oh my gosh, it's not working," and it's more than half of the time. I think that's difficult; it has to feel like the world has been turned upside down to you when you're always used to just getting stuff and just, "I get it right every time." So, I think that's what they struggle with. I tried to tell them, I said, "That's what I think we're here for is to teach you, as bad as it sounds, how to fail."

Both of these quotes demonstrate that the professors valued learning from failure and the importance of failure in design. However, none of the professors devoted any appreciable amount of their talk with students about learning from failure. Their ideas about learning from failure may have come up in other parts of the class that were not observed in this study. However, even if learning from failure did come up in other parts of the class, learning from failure during design is very important (Maltese et al., 2018; Petroski, 1992, 2006) and was missing from the professors' talk during the design projects. If students do not get exposure to learning from failure, even if the professor thinks it is important, they will not get the opportunity to learn from their failures.

THREE COMPONENTS OF SCAFFOLDING: CONTINGENCY, FADING, TRANSFER OF RESPONSIBILITY

As described in the theoretical framework, there are three major components of scaffolding; contingency: the teacher's support must be adapted to the student's level; fading: the "gradual withdrawal of the scaffolding" (van de Pol et al., 2010, p. 275) through decreasing "the level and/or amount of support" over time; and transfer of responsibility: responsibility for the performance of a task is gradually transferred to the learner (Sharpe, 2006; van de Pol et al., 2010; Wood et al., 1976).

Contingency

The professors primarily used their talk as contingent scaffolding (Sharpe, 2006; van de Pol et al., 2010), adapting their talk in the moment to fit the needs of their students. This adaptation is demonstrated, for example, in the examples in each case when the professors asked their students questions about their ideas or their progress and then gave a response personalized to where they were in the process. This pattern is further supported by their pre-interviews. All the professors said that they did not plan ahead of time what they were going to say to their students. When asked by the researcher, "How do you plan what you will say during class time? Do you specifically plan for interactions with your students, or do you allow them to arise naturally?" Professor Davis said:

> That [allow them to arise naturally]. I've been doing it long enough. I've done the same example problems enough and so now I just kind of let it flow and I watch the clock, to make sure, "Okay, this is where I need to get to."

In response to the same question, Professor Pfeiffer said:

> Yes, see that, I think in my head I think more about content. So, for example, so now I need to introduce the ideal gas equation to the students, right? [...] because I taught it a couple of times, I know from previous experience, I introduce the application and I already know what I need to emphasize when I introduce it. You know, watch out for this and this, and this is basically how I prepare it. It's more like a bullet point list, maybe, if at all, because based on experience then I basically, so to speak, have it in my mind what I need to talk about.

Professor Wilson's response to the same question was:

> I try to go live TV, it's what I call it. I try to do that as much as possible. I try to maybe put things out there, like I'll show them something, but I won't know exactly what's going to up when they pick it. Like when we talked about medical device recalls [...] I tell them, "Now, we're going to the live TV segment of class." They know what I'm talking about, so I have these things that make it humorous. I say, "We've talked about all these fundamentals, now we're going to pull up a medical device recall." I'll say, I'll let somebody in the class just say, "Okay, pick one and let's pull it up." We'll click on it and I'm seeing it for the first time just like they are. So I said, "Now we're in the live TV segment of class, I don't know what's going to happen."

All three of these quotes demonstrate that the professors value their experience in being able to talk to their students. They anticipate that their students will ask unexpected questions that they will need to use their experience to answer and adapt their teaching to accommodate these needs.

Fading

There were no clear examples of fading of scaffolding observed in any of the cases. Although both Professor Pfeiffer and Professor Wilson had examples that indicated their moves towards fading, none of the examples showed complete fading. This finding is most likely because the study was conducted over a relatively short period of time and did not represent a long enough time period for the professors to need to fade their scaffolding during this time. It is therefore a limitation of this study that we are not able to make conclusions about how the professors may or may not have changed their scaffolding over a longer period of time to incorporate fading.

Transfer of responsibility

The professors used strategies to transfer the responsibility to the students (van de Pol et al., 2010). For example, as evidenced in the example given in the results section when Professor Wilson was talking to a team about their idea related to a new technology to help healing after C-sections, he suggested they go talk to another, more advanced student who was focusing on this topic. In this example, he had already given the students their assignment and the basics on how to do it and was transferring the responsibility to them to continue the work. Another strategy the professors used to transfer responsibility was references to their future work and how they would need to take more and more ownership of their work as they advanced through the design project and through future design projects. This strategy is shown in the examples in the case description for Professor Davis that demonstrate a few of the times he referenced senior design projects or industry experiences. Additionally, the professors encouraged their students to develop unfeasible ideas that they could continue to develop as practicing engineers. This strategy is shown in the examples in Professor Wilson's and Pfeiffer's case descriptions. In using this strategy, the professors encouraged the students to think ahead to the future when they would be responsible for coming up with their engineering ideas and carrying them through. This encouragement demonstrates the transfer of responsibility from student to engineer that the students will need to go through in their careers.

SCAFFOLDING SPECIFIC TO DESIGN

All the professors took on the important role of guiding their students towards overcoming challenges in design, such as those laid out by Crismond and Adams (2012). For example, the professors supported their students towards grappling with the open-ended nature of the design projects in several ways. They sometimes explicitly told their students that it was challenging and encouraged them to take this relatively low-stakes opportunity to practice, such as when Professor Davis told a team "I'm going to leave that one up for you. I told you, the problem with these questions is there's no answers." They used their talk to ask prompting questions to further students' ideas and broaden their ideas about the applications of their ideas. Additionally, they pointed their students to other people and resources that could help support their ideas and, especially in Professor Davis's case, gave diverse examples of people and stories affected by designs. Both Professors Pfeiffer and Davis supported their students towards the practice of representing ideas towards the informed design practice to "use multiple representations to explore and investigate design ideas" (p. 748) by encouraging students to make prototypes, pointing them towards resources to construct their prototype or giving suggestions about how to use materials, and requiring them to make a poster on which they sketched their design ideas. All three professors also encouraged their students to avoid idea fixation, a common challenge for novice designers (Crismond & Adams, 2012; Faas et al., 2014; Sio et al., 2015). For example, Professor Wilson explicitly told the whole class to think about ideas that were not possible yet because they might be possible in 5–10 years when students were working in the biomedical engineering workforce. As his students were sharing their ideas and choosing teammates, Professor Davis encouraged his students to listen to many different ideas before making any decisions. Professor Pfeiffer told his students several times to "think outside the box" such as when a student asked if they could use flame throwers on their design. However, there were other patterns of beginning designers that the professors did not as thoroughly address, including problem scoping, testing and troubleshooting, and reflecting on the process.

The professors all spent very little time talking about the overall engineering design process and they did not reinforce a concrete definition of design. None of them gave specific strategies or skills for certain parts of design. They pretty much just had the students try stuff out and engaged them in conversations as they were working. Although this strategy can be effective to support students in the moment with what they need, more structured support for the entire design process could have helped them develop a more holistic understanding that could help them transfer their ideas to other contexts. In order to learn design, students must be exposed to both the knowledge about design and gain experience with the skills needed for design (Christiaans & Venselaar, 2005). The professors in this study gave very little instruction in the knowledge about design. Therefore, even though students gained experience with design, they did not get as rich of a learning experience as they could have if the professors had provided more support for the knowledge about design. This result was probably influenced by their ideas that they all had an open-ended view of design. For example, when asked "What experiences have you had with engineering design, both as the designer and the teacher of design?" Professor Davis said "...the whole definition of design. What do you mean by it because it's such a broad term?" In response to the same question, Professor Pfeiffer said, "So, well, that depends on how you define design, right?" Neither professor gave a clear definition of design and their comments demonstrated that they view design as a broad, open-ended concept. If a goal of an introductory design project like those studied in this research is to learn about the design process and be able to transfer their knowledge to different design projects, the students need exposure to and instruction in the design process.

Each of the professors focused much of their talk on the context of the problems, and all of the professors let the students chose the context for their specific project. In the mechanical engineering classes, the students were tasked to design something for people with mobility disabilities, but were not limited beyond this prompt, resulting in projects that ranged from designing kitchen tools for people that could not lift a full pot of water to ski goggles for people with limited hearing to a swing for children with limited leg mobility. In the biomedical engineering class, the students were tasked to design something that helped someone, without further restriction. The professors continued to encourage the students to focus on the context throughout the project with their talk. For example, Professor Davis used his stories to help situate each project within a larger context and encouraged the students to think more about different types of users and different applications of their ideas. The emphasis on context and on allowing the students to decide which context to focus on has implications for students' broader conceptions of engineering because it gave them opportunities to think about how their engineering work could help specific user groups and the world more broadly. It is important for students to see the broader impacts of engineering on the world (Knight et al., 2007). Context is especially important for engaging women and underrepresented minorities in engineering design (Kilgore et al., 2007) and having the professor relate learning to context may help students feel motivated to persist in engineering and see the value of considering context.

None of the professors relied heavily on technical engineering science content, instead focusing on learning objectives focused on skills such as design, teaming, and communication. For example, Professor Pfeiffer made frequent, short references to the iterative nature of design in his interactions with teams, Professor Davis spent a significant amount of his talk during the introduction of the project on teaming, and Professor Wilson emphasized the procedures involved in getting FDA approval and communicating their ideas for that approval. These skills are important for successful engineering design (ABET, 2018; Crawley et al., 2014), and it is significant that the professors emphasized these skills and guided the students through opportunities to practice them as often they are neglected among the learning of the more technical skills (Cross & Clayburn Cross, 1995). Additionally, in many engineering programs it is unclear who is responsible for teaching these skills (Paretti et al., 2011), so it is heartening to see that the professors in this study took on these challenges in the introductory course. However, in addition to learning skills such using design, teaming, and communication in isolation, engineering students also need to learn to apply these skills and integrate them with technical engineering science knowledge. Therefore, it is imperative that students have later design experiences with opportunities to integrate their design skills with technical knowledge so that students do not lose out on the important learning experience of applying their skills to other projects.

CONCLUSIONS

This study used a multiple case study approach to examine how three professors used their talk to scaffold learning during introductory engineering design projects in mechanical and biomedical engineering. Results show that the three professors used their talk to support their role as a guide and mentor to students during their projects although they had different goals with their mentoring. They used their talk to push students' ideas to consider their problems more broadly, encouraged students to brainstorm diverse out-of-the-box ideas, supported teaming, and modeled engineering language. They maintained a focus on non-technical content, including the iterative nature of design, teaming, and communication, but made references to how students would apply this knowledge in future, more technical projects. The professors supported many challenges for novice designers, including supporting prototype development to represent ideas and iterating to improve their ideas, but were not comprehensive in their support of other challenges, especially problem scoping, testing and troubleshooting, and reflecting on the process. These results indicate that professors may struggle to support these areas of design learning and may need additional support to understand their importance and how to scaffold them. Additionally, although two of the three professors explained their view of the importance of learning from failure, they did not use their talk during the design projects to directly support their students learning from their failures, indicating that professors' classroom practices do not directly mirror their learning values. The results of this study also support the importance of having multiple, different professors to gain diverse experiences with design, the importance of multiple, follow-up design experiences to apply introductory design skills, and further development of support to understand the design process more holistically. Future work should look at connections between different types of support in the classroom and student learning outcomes. Additionally, future work could focus on the follow-up of the learning in introductory design projects and how it relates to future classes and design projects.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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