COMPARING ACADEMICS AND PRACTITIONERS Q & A TUTORING IN THE ENGINEERING DESIGN STUDIO

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ABSTRACT

In the design studio, academic (professor) and practitioner tutors provide individual mentoring to students as they progress in their design projects. Prior studies suggest that design practitioners may follow a different design process compared to academics, but little is known about how this difference relates to their design tutoring. This study explores the similarities and differences in tutoring by academics and practitioners. We use a question-asking lens to characterize the tutoring styles of four tutors - two academics and two practitioners - over a five-week design project in an engineering design studio. We find that academic tutors ask questions at a significantly higher rate than practitioner tutors, suggesting a more question-centred tutoring style. We also find that proportionally more of practitioner tutors' questions are generative in nature, while the academic tutors employ more convergent thinking in their questioning. This may be an indicator of the practitioners' own design thinking, which might be more solution-focused than that of academics. These preliminary findings motivate future investigations of the relationship between differences in tutoring and impact on student design learning.

Keywords: Design learning, Design cognition, Design practice, Design studio, Question asking

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1 INTRODUCTION

While studio-based teaching and learning is a central aspect of design-centred programs, it is only recently that it is being investigated for fostering learning of design in engineering. In the design studio, tutors provide individual attention to individual or very small groups of students (Schon, 1985). Practitioners from industry and professors both are invited to tutor students, however, little is known of the impact of tutors' background (i.e., whether they come from academia or design practice) on students' learning experience in design courses. The pervasive use of virtual communication technologies, accelerated by the COVID-19 pandemic, facilitates the engagement of an ever-increasing number of professional practitioners who can act as design tutors in engineering design courses, bypassing location and time zone restrictions.

This study explores the similarities and differences in tutoring by academics and practitioners. We analyse empirical data from design sessions tutored by two academic tutors and two practitioner tutors during a five-week-long engineering design project and characterize the tutoring style of the four tutors by analysing the quantity and type of questions they direct at students. The rest of the paper is structured as follows. We begin with a brief review of the literature in Section 2 and highlight our research aims and research questions in Section 3. Section 4 details our research method, with the results presented in Section 5. Finally, Sections 6 and 7 provide a discussion of the findings and their implications, and highlight study limitations, opportunities for future research, and key conclusions.

2 BACKGROUND

2.1 Practitioners in engineering education

Professional practitioners are routinely enlisted by engineering schools to produce educational offerings grounded in practice (Akdur, 2021). They typically take on the roles of adjunct faculty members (Baukal, et al., 2011), co-instructors (Akili, 2006), or project supervisors, especially in areas that are very technically specialized (e.g., oil and gas (Ronalds, 1999) or combustion engineering (Baukal et al., 2010)). Practitioners value these opportunities as "altruistic", for example to help train the next generation of engineers, and for identifying prospective employees (Samuel et al., 2018). Senior student design projects often have industry clients; therefore, practitioners' involvement is widespread, typically in the role of the industry advisor, often a licensed professional engineer with extensive practical design experience, who along with a faculty advisor, advises the student team to develop a successful project (Knox et al., 1995; Symons and Rohl, 2020; Taylor et al., 2010).

The COVID-19 pandemic caused a global disruption to engineering education, changing expectations for instructional delivery that are likely to persist post pandemic. Many curricular milestones, such as for example public showcases of final-year design projects, had to quickly be converted into virtual affairs. The transition also had its benefits – industry representatives who are routinely invited to judge and provide feedback to student teams could more easily attend remotely (Meuth et al., 2020) and engage with student teams (Brennan-Pierce et al., 2020). While previously practitioners were typically sourced from local organizations (Knox et al., 1995), the opportunities afforded by virtual communication technologies point at an increasing role that practitioners can play in engineering design education, including as tutors in the virtual design studio (Nespoli et al., 2021), unconstrained by time and location differences.

2.2 Practitioner tutors in the design studio

One of the common features of contemporary design schools is the design tutorial, where students are individually tutored on their design project by a tutor (Lawson and Dorst, 2013, p. 224). Tutors provide regular feedback in a "learn-by-doing" atmosphere that challenges the student's work as it progresses (Crowther, 2013). Two types of tutors typically participate in engineering design teaching. The first - referred to as "academics" - are regular engineering faculty who have research training and teaching experience in engineering. Engineering faculty's typical industry experience varies between educational systems, from "career academics" with no industry experience to professors of practice or "pracademics", who enter academia after a career in industry (Pilcher et al., 2017). The tutors labelled "academics" here are those that have limited to no professional design practice experience in industry, which is especially the case with younger faculty (Fairweather and Paulson, 1996). The second are practitioner tutors, characterized here as engineers who possess significant recent professional practice (greater than 10 years) but have limited to no teaching experience. These tutors are brought into the design studio on a case-by-case basis to bring the “real-world” experience to the design studio.

The design tutorial pedagogy has recently become more common in engineering design education, but most publications focus on describing specific implementations (e.g., Tavakoli (2000), Thompson (2002), and Vrcelj and Attard (2007)). Little research to date has looked in detail at how the engagement of practitioners affects student learning (e.g., Georgilas et al. (2019)). Practitioners may not be familiar with expectations of design courses, for example they may expect complete designs (Tocco and Mata, 2012). They might also have differing views on what skills engineering education must emphasize, for example “soft” and complementary studies skills, over natural sciences (Koehn, 1995). In other words, they may emphasize professional formation rather than acquisition of mathematics, natural science and engineering knowledge. Research in architectural education, where the design studio has a long tradition and where expert tutors typically come from professional practice, has shown that while the obvious role that the tutor takes is that of the “teacher”, they may also emphasize making a good design, and sometimes even impose their own line of thought, especially when used to leading design teams in professional practice (Lawson and Dorst, 2013, p. 252).

Previous literature has compared the design cognition of practitioners (or expert designers) to that of students (or novices). Compared to students, practitioners may spend more time problem-scoping and information gathering (Atman et al., 2007), create more extensive mental representations of the problem (Björklund, 2016), and use more design strategies and rely less on trial-and-error (Ahmed et al., 2003). However, they produce a lower variety of solutions (Cash, Hicks, and Culley, 2012; Singh, Cascini, and McComb, 2021). Little is known about how practitioner tutors differ from academic tutors. Hurst et al. (2019) suggest that design practitioners may follow a different design process compared to academics. Using a case study, they compared the design processes of a team of academics and a team of practitioners and found that practitioners were quicker to construct solutions early in the design process and generally spent more time in the solution space compared to academics. This finding is also in line with a previous study investigating the impact of experience on problem/solution space exploration (Perisic et al., 2019).

2.3 Characterizing tutoring in the design studio

In the education literature there is a strong body of work on the study of tutoring effectiveness for student learning, especially in domains such as math, science, and language education. This literature suggests that tutoring provides "a social, cognitive, and pedagogical context" that enables students to "take control" of their learning (Graesser and Person, 1994). Interactions between tutors and students have been studied by characterizing their speech and dialogue patterns, including the frequencies of different speech acts (e.g., questions, directions, feedback) and turn-taking. These efforts to characterize tutor "moves" have built the foundations for the development of intelligent tutoring systems that can automate tutor feedback to scale an otherwise resource-intensive pedagogy (e.g., Lin et al. (2022), Rajan et al. (2001)).

In design education the interaction between the tutor and the student in the studio has been described as a "reciprocal reflection-in-action" (Schon, 1985), whereby through the acts of questioning and answering, telling and listening, the tutor and the student converge to a shared meaning around the design project. Questions are a pervasive form of design communication, facilitating the exchange of ideas, and ensuring participants are engaged. According to Eris (2004), designers' questioning while designing influences "cognitive aspects of their problem solving, creativity, decision making, and learning processes, and consequently, …their overall performance " (p. 11). Therefore, question-asking can be a useful lens for studying tutoring in the design studio. Eris' (2004) taxonomy, which has been widely used to characterize instructors', industry clients', and student peers' participation in design reviews (e.g., Cardoso et al. (2014), Hurst and Nespoli (2019), Hurst et al. (2021)), classifies questions into one of three categories:

- *Low-Level Questions (LLQs)*: The asker seeks information about missing details, which are known to the receiver (e.g., "When did the machine first break down?").
- *Deep Reasoning Questions (DRQs)*: Suggesting converging thinking, with DRQs the asker seeks causal explanations of given facts (e.g., "What is causing the machine to break down?")
- *Generative Design Questions (GDQs)*: GDQs encourage divergent thinking to generate different options for how the receiver can meet an objective or overcome an obstacle (e.g., "How might we fix the machine?").

In a study of students' perceptions of the usefulness of receiving the three types of questions, Cardoso et al. (2021) found that students prefer receiving GDQs over LLQs. Their suggested explanation is that GDQs might help students further develop their solution, while LLQs (especially typical clarification questions) are often for the benefit of the asker, not the receiver. In an earlier study, Cardoso et al. (2014) provide some evidence of a relationship between DRQ and GDQ questions and positive project outcomes. DRQ and GDQ-type questions may also better align with the pedagogical aims of eliciting students' reasoning (Graesser and Person, 1994). Still, LLQs can help establish a base understanding of the design details, on which more sophisticated problem analysis and solution ideation can be built.

3 AIMS AND SIGNIFICANCE

This study explores the effect of the background of who is teaching engineering design in a studio setting on design teaching and learning. We expect that the difference in the design processes followed by academics and practitioners (Hurst et al, 2019; Perisic et al., 2019) is also reflected in their design teaching and that the nature of tutoring in the studio impacts student design experiences and outcomes. This belief is also supported by our own experiences. In engineering, bringing practitioners from industry is a common practice not only in the studio pedagogy, but also in other more traditional contexts, for example as external examiners in design reviews. We have anecdotally observed differences in the types of questions practitioners and our professor colleagues ask when invited to design reviews. In this paper, we study tutor-student interactions during design tutoring sessions, focusing specifically on how tutors provide guidance through questions. Our research question is thus:

RQ: *Do academic and practitioner tutors differ in the number and type of questions they ask during tutoring sessions?*

This is an exploratory study, the purpose of which is not to measure the "effectiveness" of teaching by the two types of tutors, but rather to compare tutoring styles. Findings could support an evidence-based assessment of the impact of potential differences in teaching by the two tutor types, as well as to point to potential adjustments to the studio pedagogy to accommodate and take advantage of those differences.

4 METHOD

4.1 Data collection

The study took place in a master's level mechanical engineering course at a Canadian university. In the 12-week course, the students were expected to demonstrate the application of design methods learned in a prerequisite course. In weeks 4-9, teams of two to three students worked on an industry-sourced, case-based design project with the help of a tutor (either academic or practitioner). In this design project, student teams designed an improved automatic candy-wrapping machine for a small manufacturer of sweets. Each team completed five weekly tutoring sessions with their tutor, each approximately one hour in length. Tutors were provided with general information on the course (e.g., schedule and outline), but no guidance on "how" to tutor. In all, four teams of students (in total eight male-presenting and two female-presenting) and four tutors (all male) participated in this research study, as detailed in Table 1.

Table 1: Study participants' profiles

Team #	Size	Tutor type	Tutor profile
1	3 students	Academic	>20 years' experience in academia, with regular teaching of undergraduate and graduate design courses, little to no experience in industry
2	3 students	Practitioner	>20 years' experience in industry, little to no experience in academia
3	2 students	Academic	>10 years' experience in academia, with regular teaching of undergraduate design courses, little to no experience in industry
5	2 students	Practitioner	>20 years' experience in industry, little to no experience in academia

Data collection included video recordings of tutoring sessions, which captured tutors' and students' unimpeded natural verbalizations, sketches, and digital design representations (CAD models).

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Recordings were first transcribed automatically using Otter, and then manually checked for quality by two research assistants. The study received ethics clearance from the institution's review board.

4.2 Question-asking analysis

Question analysis was conducted in a series of steps, as visualized in Figure 1.

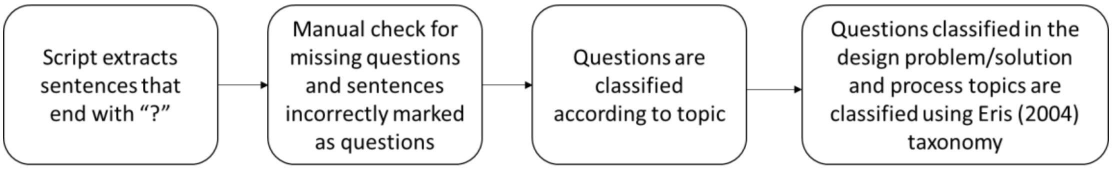

Figure 1: Data extraction and question analysis steps

First, a Python script was developed and used to extract all sentences ending with question marks. A further manual check was conducted on the transcripts and list of automatically extracted question sentences to identify false positives and false negatives resulting from mislabelled sentences (i.e., those that mistakenly had or missed a question mark). Further, during the classification process (see next step), the coders also excluded some sentences such as some that ended with "right?" since it was decided that they were the result of the tutor's communication habit instead of an intention on their part to ask a question. In total, 1602 questions were extracted, originating from both tutors and students.
The questions first underwent a classification according to their topic. Adapting a scheme introduced in Hurst and Nespoli (2019), the coders assigned each question to one of three topics:

- Topic 1 - *Problem/solution*: question relates to the design problem and its potential solutions (e.g., "How much will this component cost?")
- Topic 2 - *Process*: question focuses on the design process being followed to reach a solution (e.g., "How should we choose which component is best?").
- Topic 3 - *Meeting/course*: question is about managing the meeting (e.g., "Any questions?") or about course logistics, such as the final report and presentation of the design project.

The agreement between coders was substantial (Cohen's kappa = 0.62).
Next, the questions classified under Topics 1 and Topic 2 - 1491 in total, 1223 uttered by the tutors and 268 uttered by the students - underwent a separate analysis using Eris' (2004) taxonomy. Two of the authors had significant prior experience with this taxonomy and trained two research assistants using a training set of questions. The two coders independently classified each question as one of the three classes of questions - Low-Level Questions (LLQs), Deep Reasoning Questions (DRQs), and Generative Design Questions (GDQs) - and their subcategories. In conducting the classification, the coders could not simply rely on the participants' verbalizations as stated but needed to consider the broader context of the design project and tutoring session, sometimes even referring to the original audio file, to gain insight into the speakers' intentions and more accurately classify their utterances. Each time the two coders completed the independent coding of one team's questions, they compared and discussed discrepancies. When an agreement could not be reached, one of the authors experienced with the coding scheme and familiar with the context of the design project was invited into an arbitration session to resolve the disagreement. This process was completed four times, for each of the teams under study. Overall, the agreement between the two coders was substantial (Cohen's kappa = 0.72), when calculated at the broader level of the three classes of questions (LLQs, DRQs and GDQs). Less than 1% of the questions needed arbitration.

5 RESULTS

5.1 Question asking

Figure 2 presents the distribution of questions uttered by the tutors, normalized by the speaker's length of speech in order to calculate a "question-asking rate" (left), and by the total questions asked by the speaker, in order to better describe the distribution of their questions according to the LLQ, DRQ, and GDQ classifications (right). For ease of reading, the bars in the charts in Figure 2 and onward are presented such that teams 1 and 3 (tutored by an academic tutor) are represented by the first and second bars, while teams 2 and 4 (tutored by a practitioner tutor) are represented by the third and fourth bars.

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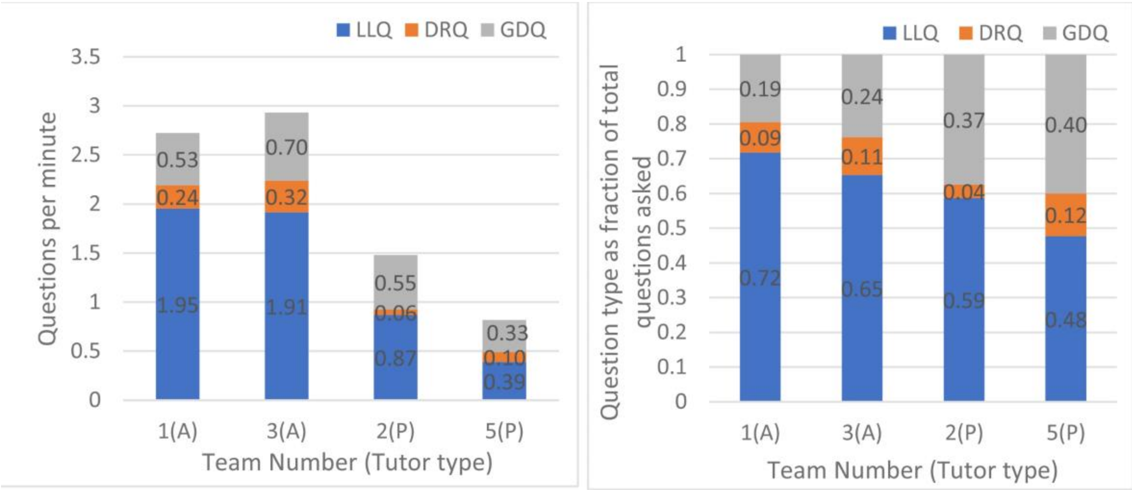

Figure 2: Tutors' questions' distribution, normalized by time spoken (left) and total questions asked (right)

Academic tutors asked questions at a faster rate compared to practitioner tutors. Academic tutors of teams 1 and 3 asked 2.73 and 2.93 questions per minute, respectively, while the practitioner tutors of teams 2 and 5 asked 1.48 and 0.82 questions per minute, respectively. Taking a closer look into the breakdown of LLQs, DRQs and GDQs, we find that practitioner tutors asked proportionally more GDQs and fewer LLQs than academic tutors. Specifically, the proportion of GDQs is 19% and 24% for the academic tutors and 37% and 40% for the practitioner tutors. Nevertheless, academic tutors ask all types of questions, including GDQs at a higher rate than practitioner tutors.

A similar analysis (Figure 3) was also conducted on the questions uttered by students, which could be addressed both at the tutor and other student(s) in their team. As expected, students ask questions at a lower rate than tutors, ranging from 0.34 to 0.73 questions per minute spoken. When looking at the distribution of questions by type, we note that the majority of their questions (67% - 76%) are of the LLQ type. We also note that students ask almost no questions of the DRQ type. We discern no obvious patterns between the question asking of students tutored by academics and those tutored by practitioners.

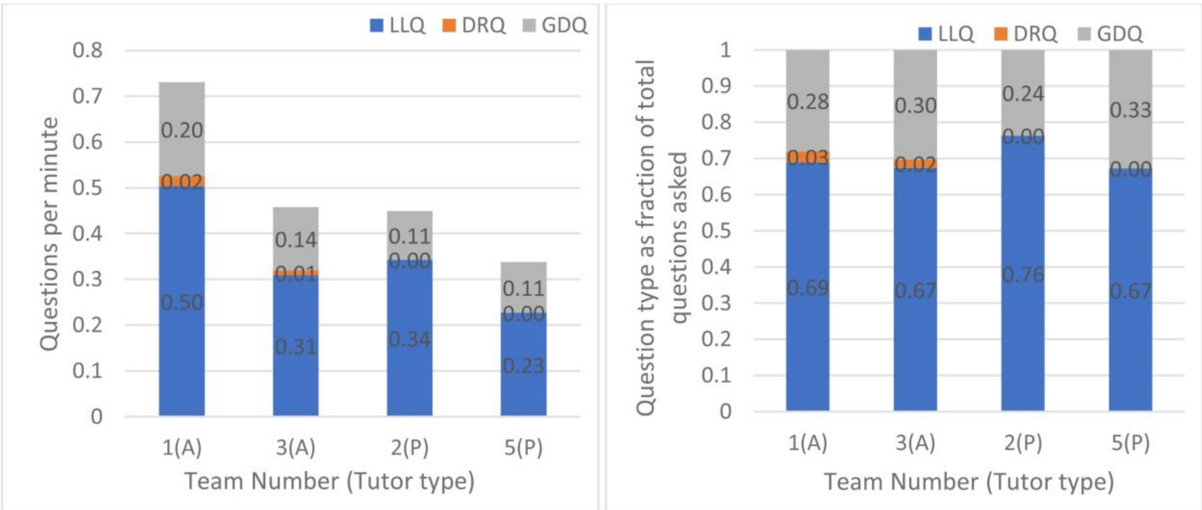

Figure 3: Students' questions' distribution, normalized by total length of time spoken (left) and total questions asked (right)

Finally, Figure 4 shows the distribution of questions according to topic (design problem, design process, or the logistics of the meeting/course) uttered by the tutors (left) and students (right). While some differences are observed between different individual tutors and student groups, we do not discern any patterns according to the tutor type.

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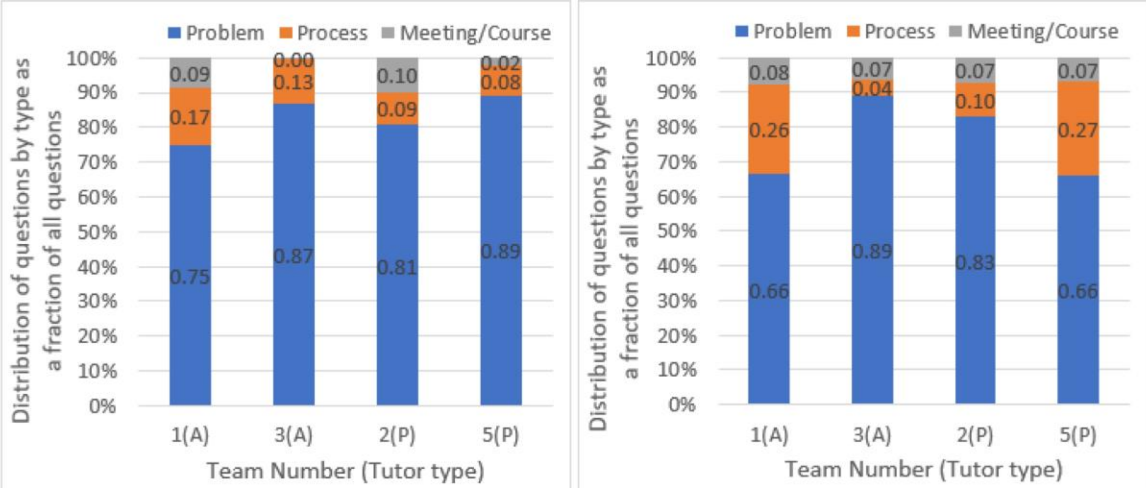

Figure 4: Distribution of question topics, uttered by tutors (left) and students (right)

6 DISCUSSION

6.1 Findings

This study aimed to characterize the differences in the tutoring style of academic and practitioner tutors in an ecologically valid engineering design studio. Verbal protocols of tutoring sessions between four student teams and their tutors were analysed using the lens of question asking, seeking to determine the differences (if any) between the frequency and nature of questions asked by the two types of tutors. Here we summarize and discuss key findings.

The first significant finding is that *academic tutors ask questions at a higher rate than practitioner tutors* - on average, 2.46 times more questions per minute. This may point at a fundamental difference between academics' and practitioners' tutoring style. A higher rate of questioning may suggest employment of the Socratic method as a pedagogical strategy. In addition, questions typically invite answers, and thus a question-centred approach to tutoring might also result in a more balanced interaction between the tutor and the student.

A second significant finding relates to the type of questions asked by the two categories of tutors. The distribution of academic tutors' questions - on average 68.5% LLQ, 10% DRQ, and 21.5% GDQ - is similar to the design instructors' distribution found in Hurst and Nespoli (2019); however, this distribution appears different from that of *practitioner tutors, who have (proportionally) on average 79% more GDQ and 28% less LLQ than academic tutors*. It thus appears that compared to academic tutors, a larger portion of practitioner tutors' questioning is divergent in nature. One explanation for this finding is that the relatively high prevalence of GDQ questions is an indicator of the practitioners' own design thinking, which might be more solution-focused than that of academics (Hurst et al., 2019; Perisic et al., 2019)

Questions were also categorized according to their topic: the design problem and its solutions, the design process, or meeting or course logistics. We expected academic tutors to ask proportionally more process questions than practitioner tutors. We reasoned that academic tutors might be more aware that the design processes itself is an important course learning outcome, and thus be more intentional in encouraging students to reflect on and discuss their design process. We also expected academic tutors to ask more meeting/course-related questions since they might have more interest in the class-related aspect of the project than tutors from industry. However, while tutors varied individually, *no differences between the two types of tutors were observed with regards to the topic of questions*.

The dataset also provided us with an opportunity to characterize the students' questions, in addition to those of the tutors. We found no differences between teams in terms of students' questioning rates, or the question types, suggesting that differences in tutors' tutoring style did not have an impact on the nature of the students' own engagement in the sessions.

6.2 Limitations and future work

We acknowledge that results presented here are based on only a sample of four tutors. This prevented any meaningful statistical analysis of the results, inviting the possibility that the differences that were qualitatively observed could be due to individual characteristics of the tutors that are unrelated to their

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academic/practitioner profile. Further, the tutors were broadly categorized into a binary academic/practitioner classification; yet it is recognized that faculty exist with mixed profiles of both academic and industry experience (Fairweather and Paulson, 1996; Pilcher et al., 2017). Nevertheless, the findings reported here can provide some insight into the tutoring styles of the two tutor types, especially when discussed in the context of prior findings on the differences in design thinking between academics and practitioners (Hurst et al., 2019; Perisic et al., 2019).

The use of Eris' (2004) taxonomy also has its limitations. We have found the taxonomy to be useful and methodologically robust across various studies (Cardoso et al., 2014; Cardoso et al., 2020; Hurst et al., 2021; Hurst and Nespoli, 2019); however, classification of questions across the three categories can sometimes obscure some of the important nuance present even in "low-level" questions. For instance, the question “Is the design safe?” is a critical question to ensure the design does not cause harm to its users; the question “How much does the design cost?” reminds the designer of the budget constraint to adhere to when designing.

Finally, in this study we do not attempt to correlate differences in tutoring to students' design outcomes. While the student teams in the study produced a design at the end of the 5-week design project, given the small sample size and the holistic assessment of the designs, a correlation analysis between tutoring styles and design quality was not suitable. At least one prior study (Cardoso et al., 2014) suggests that a higher number of DRQ and GDQ questions - "active and critical inquiry" - may be positively related to better project outcomes, however, that study was conducted in a design review rather than studio setting.

Future studies can address some of the limitations identified here by investigating differences in tutoring styles using larger sample sizes and more nuanced characterizations of the tutors' experience. Larger sample sizes necessitate the use of more automated techniques for analysing verbal protocols; fortunately, advances in natural language processing and deep learning have enabled the development of sophisticated analyses of tutors' dialogue acts across different dimensions, including questions, directives, and feedback (e.g., Boyer et al. (2010), Lin et al. (2022), Rajan et al. (2001), Vail and Boyer (2014)).

6.3 Implications for engineering design education

The application of studio pedagogy is relatively new in engineering programs, and as such deserves considered and intentional use for facilitating professional formation through designing. It is rather remarkable that while its use has been a central tradition to the design professions (architecture, industrial design), significant formalized scientific knowledge is only recently being published. Tutoring, as opposed to project managing and lecturing, cannot be an assumed skill possessed by either academics or practitioners, or tutors of a mixed profile. Our early work and that of others (Schon, 1985) suggests it can be a powerful pedagogy, but that it is nuanced, the responses by participants difficult to predict and hence the teaching opportunities for tutors unpredictable and fleeting in the moment as problems unfold. We believe that the tutor, and the knowledge, skills, and professional attitudes, that make a great tutor should be understood and therefore taught as well.

Study findings also have implications for non-studio based engineering design education settings. Different stakeholders, including professors, external reviewers, and project sponsors and clients routinely interact with students in design reviews, which are common in engineering education and practice. A better understanding of how these participants may differ in the type and topic of questions they raise in the design review can inform improved guidelines for how design reviews are structured and managed, including better guidance for participants on how to provide feedback to support student learning.

7 CONCLUSIONS

This study was motivated by a need to compare the tutoring of academics and practitioners in order to understand the impact of bringing in practitioners as tutors into the engineering design studio. The focus of the work presented here was on characterizing the similarities and differences in the tutoring styles of academic and practitioners. While the findings are limited by a small sample of just four tutors, results from a systematic analysis of the questions uttered by the tutors over a five-week design project suggest that academics' tutoring style differs from that of practitioners by a more pervasive use of a questioning as a means to guide the students in their designing. Further, practitioners' questions may more frequently engage students in divergent thinking to expand the design space, while the academic tutors employ more convergent thinking in their questioning. These preliminary findings can motivate future larger studies that can validate these results, as well as examine the relationship between differences in tutoring and impact on student design learning.

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