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Cultural Context in Engineering Design: Exploring the Influence of Communication on Design Practices

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Just as engineering designs can be uniquely created for different cultures around the world, engineers come from all over and view design through their own cultural lenses. Culture can impact how designers perceive themselves, their self-efficacy, and the way they interpret the design task at hand. Studies have shown that cultural values and behavior (i.e., cultural context) impact communication patterns, as well as learning strategies (Newman et al., 2017, "Psychological Safety: A Systematic Review of the Literature," Hum. Resour. Manage. Rev., 27(3), pp. 521–535. 10.1016/j.hrmr.2017.01.001; Hirsch et al., 2001, "Engineering Design and Communication: The Case for Interdisciplinary Collaboration," Int. J. Eng. Educ., 17(4/5), pp. 343–348). Halls' information processing continuum illuminates how some cultures communicate explicitly through written and spoken words (low context), while others communicate with a common awareness of nonverbal cues (high context) (Handford et al., 2019, "Which 'Culture'? A Critical Analysis of Intercultural Communication in Engineering Education," J. Eng. Educ., 108(2), pp. 161–177. 10.1002/jee.20254). Designers from low-context cultures are more comfortable in a low-context learning environment (e.g., with explicitly written instructions), whereas those from high-context cultures benefit more from face-to-face interactions (Goel and Pirolli, 1992, "The Structure of Design Problem Spaces," Cogn. Sci., 16(3), pp. 395–429. 10.1207/s15516709cog1603_3). These communication differences impact cross-cultural collaboration within global companies and virtual teams. This study examined whether communicating a design task in a more engaging manner would impact solution quality and self-efficacy, particularly in light of the designer's culture and/or familiarity with the design problem. Engineering undergraduate students and professionals were recruited from each of 10 countries, including the United States, to complete a design task and respond to self-perception questions. Participants were presented with the design problem in one of two modes: written (low context) or video (high context). Results showed that delivery modality and cultural context did impact design solution quality and self-efficacy; however, differences were found between professionals and students.
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1 Introduction

1.1 Motivation. Engineering design is often a highly collaborative process, engaging diverse groups of individuals to create a solution that addresses a complex problem. In any collaborative process, effective communication is critical for each participant to feel comfortable sharing ideas, giving and receiving feedback, and building on the ideas of others [1]. As Hirsch et al. [2] argue, "Engineers do not just solve problems, but they communicate solutions; that is a prominent part of an engineer's work". Communication in engineering design includes oral, written, graphical, interpersonal, and even numerical forms of communication [2], but an issue that is commonly addressed only in the context of the development of engineering education is how information is communicated to engineers and how the form of communication can impact the designer's ability to produce good design.

The social and cultural characteristics of designers can impact the result of engineering design processes. For example, these characteristics may affect how information is communicated and understood, how familiar the designer is with the context of the problem at hand, or how the designer perceives the importance or effectiveness of potential solutions. How can the culturally-based preferences among designers be addressed to create a more human-centered design problem-solving space? This study looks

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at the effect of culture on design by modifying one fundamental aspect of the design process—the way in which the design problem is presented to the designer.

Studies have shown the importance of communication within the engineering design curriculum [2], and a few have addressed how designers' culture influences design within the design process [3]. However, no prior work has addressed the interaction of the communicative delivery of the design problem and the designer's individual culture and familiarity. To do so, a design problem was formulated in writing and converted into a video presentation format. Half of the participants received the video presentation of the design task, which included visuals, a voiceover, and the same specifications outlined in the written description. The other half received the design task in written format. The study examined whether a more engaging method of communicating a design task would impact solution quality and designer self-efficacy, while also observing whether culture and/or familiarity with the design problem impacted these factors.

2 Literature Review

2.1 What Is a Design Task?. An engineering design task consists of a need or problem that the use of engineering principles can address. A design task can be well-structured, with clearly defined goals and problem states, or poorly structured, with underspecified goals and problem states [4]. Well-structured design tasks also often include other relevant external factors, i.e., context [5]. Specifications may also be included to outline the scope and requirements of the solution to reduce the number and breadth of design ideas [6].

Context, as defined by Hall, is the "information that surrounds an event" and is critical in determining the meaning of the event [7]. Similarly, explicating a design task requires more than just a statement of the specific problem to be addressed; it also requires identifying the context, or external factors, that are pertinent to all design challenges. Context can provide the designer with critical information, such as the natural and social environment in which the device or design solution will be used, as well as specific educational or cultural information about the end users. Engineering students who can provide solutions appropriate to the given context are likely to emphasize context during the initial stage of the design process [8]. Therefore, this research evaluates the solution quality of participants' final concepts based on how well they address not only the need and specifications outlined in the design task but also the context provided in the design task.

2.2 Design Task Format. Design tasks are traditionally presented to engineering students or professionals in writing, where the need or problem is given in a short statement and the specifications and context are listed out. A written format is also common for other types of educational materials used in an engineering course, such as a syllabus, handouts/notes, assignments, and exams [9]. In the engineering course setting, Pollack et al. [10] found that the format in which lectures and lecture notes are presented can be a barrier to learning, depending on the student's preference and learning style. In industry, design problems, briefs, and process documentation are often provided in written form to engineers and designers, whereas more engaging communication modes, including videos, are used for client presentations and marketing materials.

Durand et al. [6] defined a list of design problem characteristics that influence design outcomes and found that the solution quality varied among individuals when given different design problems of equivalent difficulty. The amount of variance between the design problems was measured by individuals' familiarity with existing solutions and the domain of the design problem. In this research, the participants either receive the design problem in a written format or a video format. Using Durand's list of design problem characteristics as a model, this study used a novel combination of the following factors to account for designers: (1) familiarity with the design task and known solutions, (2) cultural context, and (3) design task delivery mode. As previously noted, the design problem, context, and specifications remained constant between the written and video formats.

2.2.1 Familiarity. Researchers found that familiarity with existing solutions to the problem and the domain of the design problem resulted in different levels of access to domain-distant analogies [6]. Consequently, participants' familiarity with existing solutions and the design problem domain is a factor considered in this study. According to a study on the effect of designers' contextual experience on the ideation process, contextual experience can negatively affect creativity and novelty; however, unfamiliar context can negatively affect the designers' motivation, confidence, and mental effort [11]. These findings indicate that strong familiarity with the context of a design problem may have negative implications for solution quality, particularly in terms of creativity and novelty, while unfamiliarity with the design context of a design problem may negatively affect designer self-efficacy.

2.2.2 Cultural Context. An item listed on Durand et al.'s hypothesized list was "Are there assumed constraints due to culture" that influence design problem characteristics [6]. The researchers recommended identifying the degree and method by that culture influences design outcomes to create more equivalent problems [6]. For this reason, this study considered participants' cultural context as a factor in measuring the impacts on design solution quality and self-efficacy. Balawi et al. [12] found that learning gains were higher using an adapted design model relative to using a traditional, lecture-centered version with students in the Middle East. However, a gap was still noted between the learning gains in the courses (engineering problem-solving, physics 1, and intro to biomedical engineering) using the adapted design model compared to similar Western counterpart courses, with evidence that the differences may be due to preinstruction factors, particularly second-language issues [12]. Given the prior literature on culture and self-efficacy, there appears to be a lack of evidence showing how different cultures perceive their own self-efficacy; however, work has been done to show what affects self-efficacy in individuals of various cultures [13].

2.3 High- Versus Low-Context Model. Communication modes and information processing go hand in hand. Individuals receive, comprehend, and respond to information through either expressive or receptive communication skills. Expressive skills include those by which one produces information (i.e., speaking, writing, typing, sketching). Receptive skills include those by which one receives information (i.e., listening, reading, or following directions). Hall developed a theoretical cultural variability continuum, as outlined in his 1976 book *Beyond Culture*, based on time orientation, information processing, and communication patterns [7]. The continuum ranges from low to high levels of programmed information required to provide context, where low levels indicate an expectation that necessary information will be explicitly given, little will be assumed, and interpersonal relationships will not be paid attention to closely (low context); high levels indicate an expectation that most of the information will be implied, it will be physically externalized, and little information will be contained in the explicit message (high context). The essence of context can be summed up as what people pay attention to and what provides meaning.

Hall's theory of high-context and low-context cultures focuses on how different cultures communicate and convey meaning [7]. In high-context cultures, such as many Asian, Middle Eastern, and Latin American societies, much of the information is implicit and relies heavily on context, including nonverbal cues and shared understandings among individuals. Communication tends to be indirect, with meaning embedded in the context, relationships, and cultural norms. People in high-context cultures often value harmony, group cohesion, and maintaining social relationships.

Communication skills are emphasized differently among high-context cultures, however. For instance, Arabs are known to have an oral culture, where history, stories, and education are expressed and received in spoken word [14]. The Arab culture's focus on interpersonal skills has de-emphasized the development of reading and writing skills [15].

In contrast, low-context cultures, commonly found in Western societies like the United States and Germany, rely more on explicit verbal communication. Information is conveyed through words, and less emphasis is placed on context or nonverbal cues. Communication tends to be straightforward, with meanings explicitly stated. People in low-context cultures often prioritize individualism, clarity, and efficiency in communication.

Hall noted that no country or culture can be classified exclusively as high or low context, but that they all lie somewhere along the continuum. Hall's theory explains how cultural differences may influence communication styles, decision-making processes, and social interactions in various parts of the world. Recognizing and adapting to cultural norms and communication styles to facilitate effective cross-cultural communication and collaboration is of great value in any field. Cross-cultural communication has been researched extensively, but the backbone of this study is centered on Hall's theory of cultural variability.

2.4 Determining Context With Cultural Dimensions. Like Hall's theory, several studies have sought to understand differing values, as well as the relationship between those values, among cultures by identifying metrics. The following studies developed methods that guided how this research study determined an individual's cultural context, as well as how the design tasks were made into high- and low-context formats.

2.4.1 Hofstede's Cultural Dimensions. Hofstede's cultural dimensions and Hall's theory of high-context and low-context cultures both aim to explain and understand cultural differences, but they approach the subject from different perspectives and focus on different aspects of culture. Hofstede defined polarities observed within workplace behavior that differ based on national culture [16]. These polarities were refined and expanded to six cultural dimensions: power distance, masculinity, individualism, uncertainty avoidance, long-term orientation, and indulgence. Power distance is defined as the inequality between people based on prestige, wealth, and power. Uncertainty avoidance is how people behave in unstructured or high-risk situations. Individualism/collectivism is a culture's tendency to instill and promote individual thinking or group thought. Masculinity/femininity is a culture's tendency to be characterized by assertiveness, advancement, and earnings (masculine) or nurturing, interpersonal sensitivity, and orientation to service and physical environment (feminine). Countries with collectivist cultures and strong uncertainty avoidance tend to require high-context communication to govern [17]. This research draws upon Hofstede's dimensions of individualism, uncertainty avoidance, and long-term orientation, using proxy variables defined by Stull as outlined in the following section [18].

2.4.2 Stull's Proxy. Stull identified proxy variables for Hofstede's cultural dimensions that serve to measure an individual's cultural context. Rather than coding for the eight cultural dimensions, Stull found that birthplace, number of family generations born in the United States, languages spoken, culture identified with, and exposure of other cultures could be used to identify one's cultural context. Stull used a 40-item Likert scale survey to compare Hofstede's six cultural dimensions to the above five variables. Individuals born in the United States tended to agree more with individualism, high-risk-taking, low power distance, and masculinity/femininity statements compared to those raised elsewhere [18].

2.4.3 Minkov and Kaasa's 2D Cultural Dimensions. While Stull's proxies simplify Hall's metrics to gauge an individual's cultural context, Minkov and Kaasa [19] used information related to birth country to further distinguish cultural values. In addition to Hofstede's dimensions, this research draws upon the individual's birthplace and culture identified with to assess their cultural context.

Similar to Stull, Minkov and Kaasa revised Hofstede's six cultural dimensions into a 2D model that has been validated for objectivity. The model indexes countries based on a scale from individualism (IND) to collectivism (COL), as well as a scale from flexibility (FLX) to monumentalism (MON) [19]. Individualism is characterized by cultures that allow individuals to exercise freedom, rights, and autonomous thinking, and to challenge conventional thinking. Collectivism is characterized by societies that impose rules on behavior and do not tolerate deviation from cultural norms. An example of a highly scaled individualistic country is the Netherlands, while an example of a highly scaled collectivist country is Qatar. Flexibility and monumentalism differ based on societies' prioritization of delayed gratification and thrift. These two measures are based on Hofstede's dimension of time orientation, where long-term orientation corresponds to flexibility and short-term orientation corresponds to monumentalism. Time orientation is extracted from a culture's teaching on personal values, self-construal, parental advice for children, work goals, and results from the World Values Survey. Societies that are rated as flexible prioritize thrift and self-sufficiency, whereas monumental societies prioritize generosity and economic interdependence. An example of a highly scaled flexibility country is Japan, while an example of a highly scaled monumentalism country is Haiti. This study uses the social orientation and time orientation scores for each country based on Minkov and Kaasa's findings.

2.5 High- and Low-Context Educational Practices. This section discusses how Hall's cultural variability theory has been applied to educational practices, highlighting instances of high-context educational methods and their impacts on students.

Culture is made evident through communication by "established patterns of meaning, thinking, feeling, and acting" [20]. Adopting a universal system for communicating that disregards these learned patterns results in confusion and unmet expectations. For instance, a high-context individual might tend toward more elaborate explanations, taking their time to make a point, and does not tend to be very specific in their explanations. On the receiving end, however, a low-context individual may be expecting a brief, clear, and concise statement that quickly reaches the point.

Considering engineering design with respect to cultural differences, a school in the UAE adapted the Western model to the Arab culture. It noted that students embraced teamwork, competition, and oral presentations, and resisted open-ended questions [15]. This finding is consistent with studies on cultural dimensions, where those from a higher context culture tend to be resistant toward risk-taking and uncertainty [16,17].

Within the educational setting of English as a Foreign Language for Japanese students, the question of how much low-context cultural understanding should be taught when teaching high-context students has been asked. Bent [21] recommended that instructors tailor their teaching methods and expectations to the cultural context of the student population. One goal of this research is to gain a better understanding of how high/low instructional methods in design affect engineers from different cultural contexts.

A chemistry course in Qatar adapted a student-centered teaching method known as process-oriented guided inquiry learning (POGIL) to be more compatible with their students' high-context culture [22]. POGIL validates group values, roles, and decisions through small group-centered learning. In Qatar, collaborative endeavors are highly valued due to the shared cultural background and language among students. Studies indicate that individuals from high-context cultures, such as Qatar, benefit from immersive learning environments that promote peer interaction [23]. Qatar's collectivist cultural orientation fosters comfortable group work dynamics, allowing students to engage in discussions and share findings in

their preferred language [24]. Implementing POGIL for high-context students resulted in improved scores and self-efficacy, and increased interest in the material [23].

Similarly, a proof-of-principle was developed that showed alternatives to traditional, lecture-based course structures can be implemented in the Arab Gulf context through problem-based learning (PBL). Design problems were thoughtfully chosen considering their cultural and societal significance, with a focus on addressing relevant issues in the UAE. Students' learning and attitude improved as a result of the PBL instruction [12].

Westbrook explored the implications of low-context, text-based learning on intercultural online education. Inequity can arise if a student from a high-context culture expects face-to-face communication with a professor to fully disclose expectations and, therefore, overlooks written handouts like the syllabus. When comparing students in a collaborative setting, those from a low-context culture participated to demonstrate what they know, whereas those from a high-context culture would only participate when they believed they had something to add. Results from a study analyzing high-context students' performance in an online course suggested that students could benefit from course assessments and activities incorporating multicultural ways of knowing, as well as utilizing video technology to encourage more visual, nonverbal communication [9].

Nathan's *Foundations of Embodied Learning* [25] describes how people process and acquire new information through socially and culturally embedded activity. His theory of the sociocultural basis for learning holds that, for new knowledge to become meaningful, it needs to connect with an individual's shared ways of knowing since "mental processes are deeply situated, highly contextualized, culturally embedded, and physically extended." This theory could be incorporated into the design process through reframing the details of a design problem, particularly ones used in a design course, to better suit one's culture (i.e., changing the geographical setting of a problem to match the climate and culture of the students' culture).

The principle of concreteness fading, as suggested by Bruner, is a process in which the tangible representation of a concept gradually becomes more abstract [26]. As an instructional approach, concreteness fading utilizes students' genuine encounters with familiar objects and situations to bolster a solid interpretation of formal concepts for generalization and transfer. Especially in the teaching of the design process, communicating ideas to students first in a physical representation and progressing to the abstract could benefit students' ability to process the content. This research has utilized Nathan's sociocultural basis for learning and Bruner's principle of concreteness fading by altering the way information is given to the designer to be more engaging and less cognitively demanding. Nathan's [25] view on embodied learning guided the hypothesis that high-context design problem representation will positively impact the designer, regardless of their culture. This is because the cognitive load is higher when listening to a lecture or giving a presentation than when engaging in conversation [27].

2.6 Self-Efficacy and Quality. Bandura emphasized that self-efficacy influences how people think, feel, motivate themselves, and behave [28]. Higher self-efficacy leads to greater effort, persistence, and resilience in the face of trials, while lower self-efficacy can result in avoiding challenges and poorer performance. Hofstede's cultural dimensions, namely power distance, uncertainty avoidance, masculinity, and individualism, affect efficacy by influencing an individual's creative skills and task motivation [29]. Gong developed a visualization framework to explain the relationship between culture and creativity using the componential theory of creativity and Hofstede's cultural dimensions. The theory holds that an individual's educational level affects their *perception of their experience* of creativity. Rather than measuring creativity through creative outputs or divergent thinking, Gong et al. [30] focused on how the creative process was experienced.

Research indicates that individuals from high-context cultures judge creativity based on *how appropriate the result is*, while low-context individuals are more focused on the *novelty of the result* [31,32]. Thus, the way students perceive creative efforts differs among cultures. Arab students gained confidence in design when given a problem that connected to their authentic community, not just within the classroom setting [13]. Glaveanu [33] emphasizes that creativity should be seen through the context of the creator's culture. Consequently, creativity per se is not used as a metric in this study, since participants are of many different cultures. Rather, participants' perception of their self-efficacy is measured alongside solution quality.

3 Research Questions and Hypotheses

A study was developed to identify how culture and communication affect engineering design and designer self-perception. The following research questions and hypotheses were explored:

(1) How are design solution quality and designer self-efficacy affected by participants' combined familiarity with the design task?

H1: Higher combined familiarity will correlate to a higher solution quality [6,34] and self-efficacy score [35].

(2) How does the design task delivery modality (video versus written) affect the designer's solution quality and self-efficacy?

H2: The high-context delivery modality (video) will correlate to higher solution quality, since the video is more engaging. Embodied learning and contextual learning research suggests that participants in general respond more to engaging, context-relevant learning environments, so participants who received the video delivery mode, regardless of cultural context, will have higher solution quality and self-efficacy than those who received the written delivery mode [25]. Engineering professionals will not experience as much of an effect from the delivery modality as undergraduate students, since they most likely have more design experience and receive more diverse modes of design task delivery in their work environment. The more experience a participant has with design should result in higher-quality design solutions [36].

(3) How does the designer's cultural context affect their solution quality and self-efficacy?

H3: The prior literature on the effect of culture on self-efficacy indicates that various cultures perceive self-efficacy differently. Participants from low-context cultures will have higher self-efficacy due to the value of individualism in low-context cultures [37]. Self-efficacy will be equally affected by cultural context for students and professionals, as no literature has been found to indicate otherwise. Higher solution quality is anticipated for participants from low-context cultures due to the correlation between low-context culture and risk tolerance.

(4) How do cultural context and delivery modality interact in their effects on solution quality and/or self-efficacy?

H4: Studies have shown a positive impact of tailoring educational instruction to fit the culture of the students [12]. Participants from a high-context culture who receive the video delivery mode will correlate to higher solution quality and self-efficacy than the high cultural context participants who receive the written delivery format [9,13].

4 Methods

4.1 Study Design and Data Collection. This study was conducted under the guidance of the Institutional Review Board at the University of Wisconsin-Madison. Informed consent was obtained from all participants at the start of the participant selection

survey. Data from prospective participants was collected through a Qualtrics survey administered using Prolific, an online subject recruitment service that allows researchers to compensate participants for completing the survey. Prospective study participants were paid $10 to complete the Qualtrics survey, averaging 30 min in length. Prospective participants were filtered in Prolific based on whether they said that they were either currently studying engineering or were working full time in mechanical, electrical, chemical, or civil engineering roles. An additional screening question was used to select undergraduate students currently studying mechanical engineering and professionals currently working in Mechanical, Electrical, or Civil engineering positions to ensure exposure to the engineering design process.

The study was divided into three segments: pretask questions, the design task, and posttask questions. In the first segment, participants were asked about their experience either as a student or a professional, as well as information used to identify the participant's cultural context (see Appendix A). They included questions related to:

- Comfort with risk-taking
- Preferred mode of expressive communication (sketching, writing, or speaking)
- Preferred mode of receptive communication (written, audio, visual)
- Birth country
- Country that participant most identified with culturally

In the second segment, participants were given the design task in one of two modes: written (low context) or video recorded (high context). The written format is provided as Appendix B. The video format provided the same information and design problem. Participants were asked to brainstorm potential solutions for 10 min, after which they submitted their brainstormed ideas, as well as a final concept, either via a file of their labeled sketches or a written description. If they were unable to upload photos, they were asked to provide a written description.

In the final segment of the study, participants were asked questions about familiarity, perceptions, and their demographic characteristics. The familiarity and perception questions were presented with a sliding bar to allow participants to choose a percentage between 0 and 100. They included questions related to the participant's prior experience with the design task, confidence in their selected concept, how creative they believed their concept was, how much they enjoyed solving the problem, how comfortable they were in brainstorming ideas, and the quality of their concept. The demographic information obtained included age, gender, ethnicity, first language, other spoken languages, age English was learned if English was not the first language, birth country, and whether they identified with the culture of their birth country or another country. A flowchart depicting the study design can be seen below in Fig. 1.

The relationship between how the design task was delivered (written or video) and the participant's identified cultural context was investigated using the following metrics: design solution quality, self-efficacy perception, and expertise as a professional or student. It is expected that those from a more high-context culture will tend to prefer engaging communication modes like video, over more detached forms of communication like email or written documents.

Perceived self-efficacy was calculated based on the average response to the posttask perception questions: perceived quality of design solution, confidence in selected concept, perceived creativity of selected concept, enjoyment of solving the design task, and comfort in brainstorming ideas for the task.

Lastly, familiarity was scored based on responses to Yes/No questions following the design task. The design quality, calculated self-efficacy, and familiarity score were compared to identify any differences or patterns between engineering students and professionals.

4.2 Design Task. The chosen task for this study was to design a milk frother. The milk frother design task was selected because it would require minimal engineering knowledge to provide a solution. It was modeled after the design task in Toh and Miller's [38] study on design concept selection. Specifically, participants were asked to design an innovative device for the home that froths milk in a short amount of time using the following specifications:

(1) The device should be compact in size, either handheld or no larger than an average smoothie blender (9 in × 11 in × 14 in/ 23 cm × 28 cm × 35 cm).
(2) The device should be low cost but durable.
(3) The device should be easy to clean.
(4) The device does not need to heat or cool the milk necessarily; milk can be preheated/cooled.
(5) The device should create finely textured microfoam.

4.3 Demographics. There were 179 participants who started the study by taking the pretask questionnaire, but only 121 participants were included in the data analysis due to partial or repeated responses from 58 individuals. The participants were asked their age, gender, race/ethnicity, first language, other languages spoken, what country they were born in, and whether they identify with the culture of their birth country. The student participants were asked how many years they have been working on their undergraduate degree, including the current year. The professional engineers were asked to select which option best described their day-to-day activities as an engineer (mostly in office, mostly visiting clients in office, mostly visiting clients off-site, all equally). The summary of the demographics of the participants is shown in Table 1.

4.4 Context Metrics

4.4.1 Country of Residence. For this study, participants were selected from the following countries of residence: Australia, Canada, Chile, Israel, Japan, Mexico, New Zealand, South Africa, South Korea, and the United States. A person's country of residence

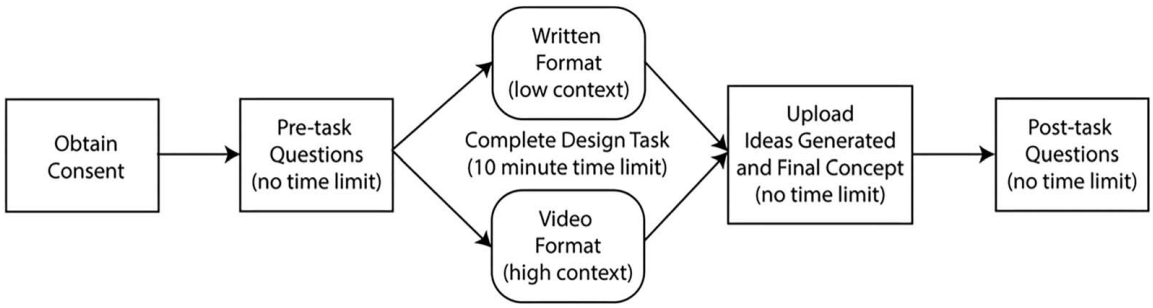

Fig. 1 Study design flowchart

Table 1 Summary of participant demographics

Participant age	20–22 years	23–25 years	26–29 years	30–39 years	40+ years
Number of participants	31	17	22	31	20
Participant education/experience	Undergraduate students		Professional engineers		
Number of participants	1–3 years		4–8 years		
	24	33	64		
Professional participant work activities	Most time spent working in office	Most time spent off-site with clients	Most time spent in office with clients	Equal time spent among all three options	
Number of participants	32	10	1	21	
Participant cultural identification	United States	South Africa	Canada	Mexico	Australia	Other countries
Number of Participants	32	31	15	8	8	94

provides insight into the culture in which they are currently immersed. Unless the participant reported that they most identify with that country's culture, the country of residence was used primarily for the initial screening process to select study participants. The countries of residence from which participants were chosen were intended to provide a range of cultural contexts, assuming that most participants would identify with the culture of their resident country.

Three survey clusters were created based on Minkov and Kaasa's 2D cultural model ratings by country. The first cluster included Mexico, Chile, and South Africa. These countries all had high ratings of collectivism and monumentalism. The second cluster included Japan, South Korea, Australia, Canada, Israel, and New Zealand. These countries all had high ratings of individualism and flexibility. Originally, Japan and South Korea were grouped separately because they have much higher flexibility ratings than the others; however, the available subject pool was too small. The US participants were grouped separately as a control for comparison between cultures outside of the United States. Table 2 provides the individualism/collectivism and flexibility/monumentalism ratings for each country.

4.4.2 Country of Identified Culture. A demographic question asked if the participant identified with the culture of their birth country, and, if not, with which country's culture they identify. The country's culture that the participant identified with was the country used to score the cultural context of each participant using the same individualism/collectivism and flexibility/monumentalism metrics shown in Table 2.

Each participant's score for the country of culture identified with was based on Minkov and Kaasa's 2D model, where they scored 102 countries on a scale from individualist to collectivist, based on national indicators. Countries with a high individualist score received a 0; otherwise, they received a 1. If the country was not provided in Minkov and Kaasa's model, the country's score of the most similar culture was identified by using the Country Comparison Tool [39].

4.4.3 Comfort With Risk-Taking. One of Hofstede's dimensions of culture, uncertainty avoidance, was used to strengthen the validity of the cultural context score, as high-risk takers are correlated with individualistic traits. Participants were asked to rate their comfort with risk-taking on a sliding bar scale from 0 to 100. Participants were scored as high risk if they responded 50 or greater on the scale and low risk if they responded less than 50 on the scale.

4.4.4 Communication Preferences. Communication preferences were used to distinguish individuals of high- and low-context culture. Communication preferences included both expressive and receptive forms of communication, where participants identified their preferred mode of expressing their ideas (sketching; writing; or speaking) and receiving information (written in emails or letters; audio, including voice calls and messages; or face to face, either in person or through video calls).

If the participant selected "writing" or "sketching" as their preferred mode of communicating their ideas, they received a score of 0 for their expressive communication preference; otherwise, they received a 1. If the participant selected "written" as the form of communication they preferred to receive, they were given a score of 0 for their receptive communication preference; otherwise, they received a 1.

An overall score for the high- and low-context metric was developed using the 0/1 context scores for the following high- and low-context subfactors: country of identified culture's social orientation (collective versus individual), country of identified culture's time orientation (monumental versus flexible), comfort with risk-taking,

Table 2 Scores on individualism–collectivism and flexibility–monumentalism

Country	+IND–COL	+FLX–MON
Mexico	−63	−104
Chile	−8	−153
South Africa	−105	−126
Japan	42	234
South Korea	25	174
Australia	83	41
Canada	78	31
Israel	16	2
New Zealand	68	37
United States	33	11

Table 3 High- and low-context categories of cultural context subfactors

Cultural context subfactor	High-context category	Low-context category
Expressive communication	Speaking	Writing, sketching
Receptive communication	Face to face, audio	Written
Risk tolerance	Risk averse	Risk tolerant
Social orientation	Collective	Individual
Time orientation	Monumental	Flexible

preferred mode of expressive communication, and preferred mode of receptive communication, as outlined above and summarized in Table 3.

If a participant was identified as high context for two or more of the cultural context subfactors, they were designated high context; otherwise, they were designated low context.

4.5 Solution Quality Metrics. Each participant submitted their brainstormed ideas, as well as a final design solution. Some participants provided more detail in the brainstorming portion, so if the final design solution did not answer a question on the rubric, the brainstormed ideas were referenced. The final design solution was scored for quality based on a rubric created by the researchers to reflect the specifications provided. Each design solution was reviewed by one rater and given a score from 0 to 9. A second rater scored 25% of the solutions, and interrater agreement was used to ensure a standard measure of solution quality. Both raters were graduate-level researchers in engineering design. The final rubric and scoring obtained a Cohen's kappa value of 0.72.

4.5.1 Quality Rubric. Each solution was rated for quality based on how well the outlined need, specifications, and context were met and addressed. The quality rubric, shown in Table 4, was developed by the researchers to include a rating category for each of the specifications outlined in the design task, including size, cost, durability, ease of cleaning, and design for microform. The rubric was refined twice in the process to achieve acceptable Cohen's kappa values in the interrater agreement.

Each design was scored for each rating category listed in Table 4, as follows:

- If the design did not label or include the material to be used, or if the material was not considered durable (e.g., stainless steel and thick glass), the score for "durable material defined" was 0; otherwise, the score was 1.
- If the design contained several complex parts that would require high manufacturing costs or intricate assembly steps, the score for "simple to manufacture" was 0; otherwise, the score was 1.
- If the design did not appear to be able to be cleaned in 60 s or less (for example, a blender where the lid is attached to the blades and unscrews for quick cleaning), the score for "ease of cleaning" was 0; otherwise, the score was 1.
- If the design did not include a function that specifically incorporated air from the surface of the milk to beneath the surface to indicate microfoam creation was possible, the score for "intentional microfoam" was 0; otherwise, the score was 2. Including an intentional microfoam creating function was given double weight, as it was a critical specification for the design task.
- If the design was not detailed from start to finish, meaning the operating process could not be followed from power to output, the score for "comprehensive" was 0; otherwise, the score was 2. The "comprehensive" score was given double weight, because it was important that the design could be followed from power to output to understand functionality.
- If the design included aspects that were unachievable, or a lack of details left gaps in the operability of the design, the score for "feasible" was 0; otherwise, the score was 2. The feasible score was also given double weight as it was important that the design obeyed physical laws to be functional.

4.5.2 Sample Design Solution and Sample Rubric. Figure 2 is a sample design solution submitted by one of the professional participants who received the video delivery mode of the design task and was labeled as low context.

Table 5 shows the scoring of the design sample within the quality rubric. The quality score of the sample design solution was 8 out of 9, well above the group average of 4.188, because it included a durable material (rubber), had an accessible frother for cleaning

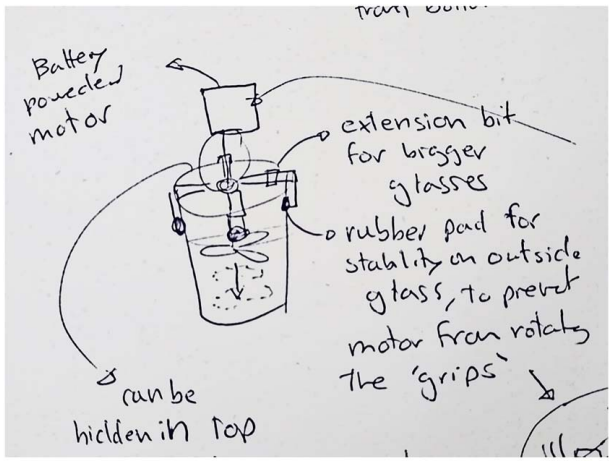

Fig. 2 Sample solution by a low-context professional participant receiving a design task by video

Table 4 Solution quality rubric

Categories	Explanation	0 (not present)	1 (present)
Durable material defined	Material was considered which suggests durability and cost		
Simple to manufacture	Few/simple parts, low-effort assembly		
Ease of cleaning	Simple to disassemble and parts to be cleaned are accessible		
Intentional microfoam (double weight)	Explicitly built in movement that brings air from the surface of the milk beneath the surface		
Comprehensive design (double weight)	Operating process is outlined from power to output		
Feasible (double weight)	achievable, sufficient details provided to perceive the operability of the design		

Table 5 Sample design solution quality rubric

Categories	Guiding Explanation	0 (not present)	1 (present)
Durable material defined	Material was considered which indicates the design's durability and cost		1
Simple to manufacture	Few/simple parts, low-effort assembly	0	
Ease of cleaning	Simple to disassemble and parts to be cleaned are accessible		1
Intentional microfoam	Explicitly built in movement that brings air from the surface of the milk beneath the surface		2
Comprehensive design	Operating process is outlined from power to output		2
Feasible	Achievable, sufficient details provided to perceive the operability of the design		2

purposes, was designed to move up and down to create microfoam, included extensive labeling (not shown), and was comprehensive and feasible given the details in the labels. The design did not meet the requirement to be simple to manufacture, as it described the whisk moving up and down, which would require a battery-powered extendable arm, exceeding the rubric's definition of low-effort assembly and few complex parts.

4.6 Self-Efficacy Metrics. A desired quality for all engineers is self-efficacy. Confidence in one's ability to perform well can influence performance, persistence, and resilience. Perceived self-efficacy was scored based on participants' responses to perceptual questions related to design and creativity. Questions 7–11 in the posttask questions were slider bar questions from 0 to 100; the calculated self-efficacy was the average of these responses. The questions asked were chosen from larger surveys found in the literature [40–42].

4.7 Familiarity Metrics. How familiar the participant was with the context of the design task was measured to account for possible bias in the design process, as well as to consider alongside solution quality and expertise. Each participant was scored based on their responses to the Yes/No familiarity questions in the posttask section. The score was based on the total number of "Yes" responses to posttask questions 1–6, including whether they had ever seen or used a milk frother before, if they had ever frothed milk in a drink, if they had considered this design task before, if they had enough time to solve the problem, and if they knew of current solutions on the market. These questions were based on prior work by Morkos and Summers [43]. If the participant answered "Yes" to three or more of the familiarity questions, they were labeled as familiar (given a score of 1); if fewer than three questions were answered "Yes," the participant was labeled as unfamiliar (given a score of 0).

4.8 Data Analysis. Statistical analysis of the data collected was conducted using R 4.3.2 and R Studio. Statistical tests were utilized to assess the between-subjects impacts of the independent variables (cultural context, delivery modality, and combined familiarity) on the dependent variables (solution quality and calculated self-efficacy).

First, all data were tested for normality using the Shapiro–Wilk test for normality and homogeneity of variances using Levene's test. Calculated self-efficacy was normal for all independent variables and homogeneous for all independent variables except the student cultural context subfactors: time and social orientation variables. Solution quality was nonnormal and nonhomogeneous for all independent variables.

For all categorical data, the Fisher's exact test was used. The strength of association found from Fisher's exact test was determined using odds ratios. The odds ratio is a statistical measure used to assess the strength and direction of associations between two variables in a case-control study or logistic regression analysis. It represents the ratio of the odds of an event occurring in one group compared to the odds of it occurring in another group. The odds ratio quantifies the likelihood of an outcome (e.g., presence or absence of a certain characteristic) given exposure to a particular factor, relative to the likelihood of the same outcome in the absence of that factor. It helps determine the magnitude and direction of the effect of the independent variable on the dependent variable. A value greater than 1 indicates a positive association, while a value less than 1 indicates a negative association.

Specifically, Fisher's exact tests were run for the five individual survey questions that made up the self-efficacy score. Each question was provided with a slider bar from 0 to 100 for participants to rate according to their perception, but for the analysis for significance, responses were binned into four groups: 0–25, 26–50, 51–75, and 76–100. Each response was compared to the independent variables, including the cultural context subfactors, to reveal if there was a significant relationship. To use a 2×2 contingency table to determine the strength and direction of significant associations, the survey responses were binned into two groups: 0–50, 51–100, and the solution quality scores were binned into two groups: 0–4 and 5–9.

For continuous data with two groups, Welch's two-sample *t*-test was used, and for more than two groups, the analysis of variance (ANOVA) test was used. The strength and direction of association for Welch's two-sample *t*-test was determined by which group had the higher mean value, whereas the strength and direction of association for the ANOVA test results were inferred from the differences in means between groups associated with each factor. In determining an interaction between two nonparametric independent variables, an ordinal logistic regression model was used, followed by a Bonferroni test for association. A threshold of $p = 0.05$ was used to gauge the significance of each variable. For variables resulting in a *p*-value below a threshold of $p = 0.1$, additional Bonferroni tests were run to investigate potential interactions for a subset of variables.

For the independent variables with two groups, Welch's two-sample *t*-test was used to analyze potential significance between self-efficacy and cultural context, comfort with risk, time orientation, social orientation, delivery, and combined familiarity. For the independent variables with three groups (expressive and receptive communication), an ANOVA test was used to analyze the potential significance between self-efficacy and expressive and receptive communication preferences. Cultural context subfactors were also analyzed for association with the dependent variables.

5 Results

The study found that delivery modality and risk tolerance (a cultural context subfactor) influenced professionals' solution quality but had no significant impact on students. Unexpectedly, professionals were more affected by delivery modality, despite their presumed familiarity with various communication methods. Self-efficacy in professionals was influenced by their social orientation —those identifying with collective cultures had higher self-efficacy, which contradicted the assumption that individualist, low-context individuals would score higher. For students, familiarity with the design context positively impacted self-efficacy, as expected. However, students from high-context cultures reported higher perceived quality and self-efficacy than their low-context counterparts, which was contrary to predictions. This trend was further supported by findings that both students and professionals from monumental and collective (high-context) cultures demonstrated higher calculated self-efficacy, challenging assumptions favoring individualist, low-context cultures. Further details on the results as organized by research questions are found in the subsections below.

5.1 Research Question 1: Solution Quality, Self-Efficacy, and Design Task Familiarity. The first research question identified by this study is: *How are design solution quality and designer self-efficacy affected by participant's combined familiarity with the design task?*

This question was addressed by measuring the association between designers' combined familiarity scores with their solution quality scores and calculated self-efficacy scores. The designer's combined familiarity score represented the total number of "yes" responses to the posttask questions related to the participant's familiarity with the design task at hand. The study hypothesized that higher combined familiarity scores would correlate with higher solution quality and efficacy scores.

5.1.1 Design Solution Quality and Participant's Familiarity With the Design Task. Figure 3 shows the average solution quality for professional and student participants according to whether they were identified as familiar or unfamiliar with the task based on their combined familiarity score. Among all groups, there were no statistically significant relationships found between combined familiarity and design solution quality using Fisher's exact test.

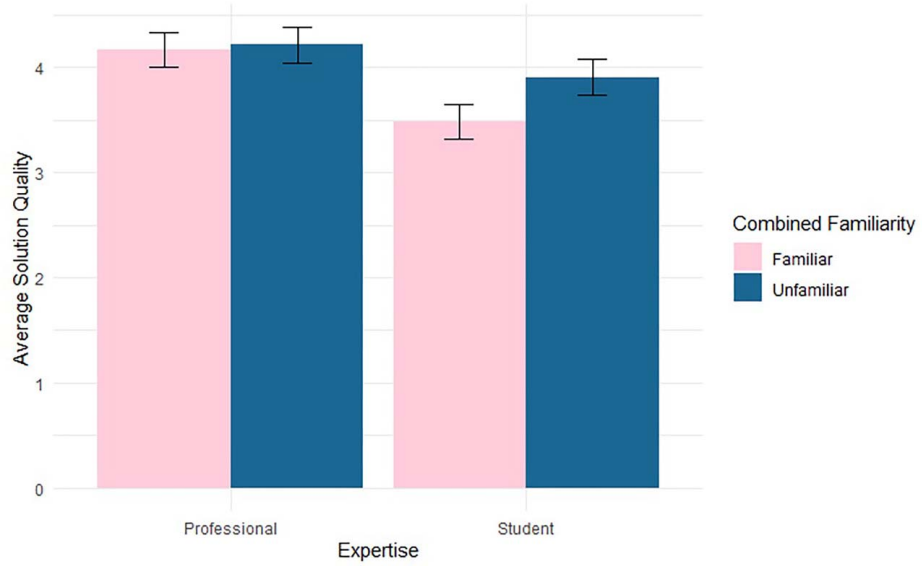

Fig. 3 Average solution quality by expertise and combined familiarity groups. Error bars show ±1 SE.

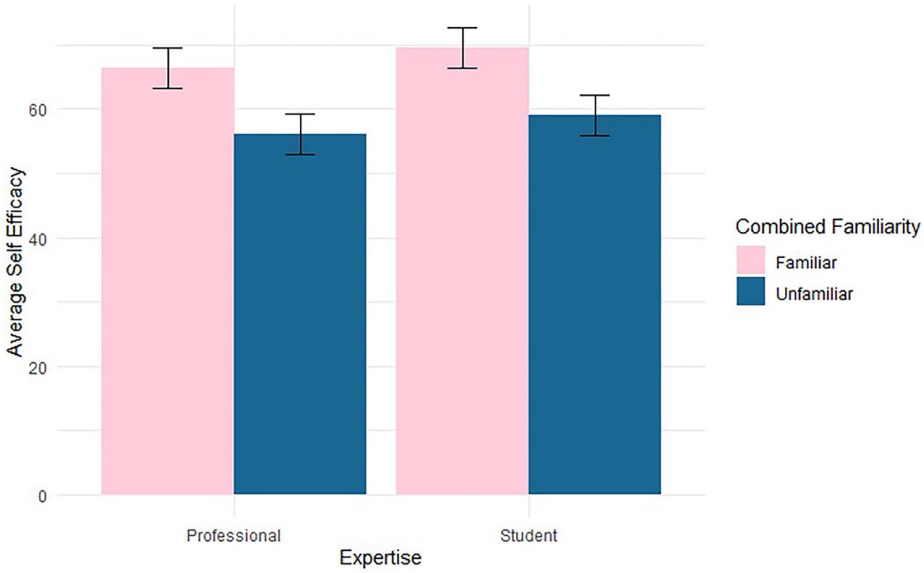

Fig. 4 Average calculated self-efficacy by combined familiarity and expertise groups. Error bars show ±1 SE.

5.1.2 Self-Efficacy and Participant's Familiarity With the Design Task. Figure 4 shows the average calculated self-efficacy between professionals and students compared to combined familiarity. Combined familiarity is differentiated with separate colors since familiarity is not related to high or low context. Among the student participants, statistical significance was observed between calculated self-efficacy and combined familiarity ($p = 0.008$) using Welch's two-sample t-test. This indicated that, for students, familiarity with the task was related to higher self-efficacy scores. The same relationship was not found among participants who were professionals.

5.2 Research Question 2: Solution Quality, Self-Efficacy, and Delivery Modality. The second research question posed by this study was: *How does the design task modality (video versus written) affect solution quality and the designer's self-efficacy?*

This question was addressed by examining the relationship between the delivery modality of the design task and the designers' solution quality scores and calculated self-efficacy scores. The study hypothesized that high-context delivery modality (video) would correlate with higher solution quality and self-efficacy because video is more engaging than written documents. However, it was further hypothesized that the effect of the delivery modality on solution quality would be greater among students than engineering professionals because professionals have more design experience and have been exposed to more modes of design task delivery.

5.2.1 Design Solution Quality and Delivery Modality. Examining the relationship between solution quality and delivery modality, Fig. 5 shows the probability of achieving a higher design solution quality depending on modality for professionals and students. Fisher's exact test was applied to the categorical data for

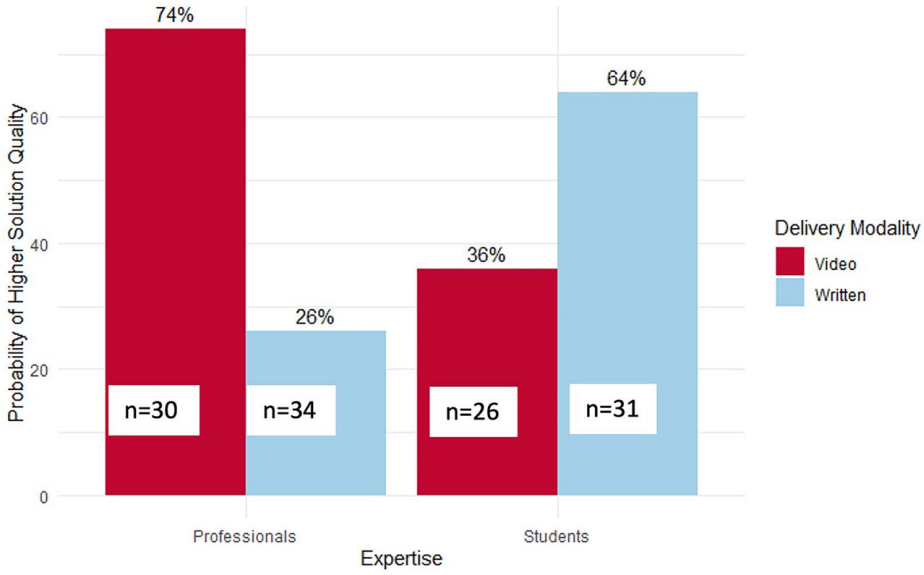

Fig. 5 Probability of higher solution quality by expertise and delivery modality groups

solution quality and delivery modality. For professional participants, there was a statistically significant relationship between solution quality and delivery modality ($p = 0.001$), whereas the results for students did not show a statistically significant relationship. Contrary to this study's hypothesis, professional participants showed a strong, positive association between solution quality and video delivery mode (odds ratio = 2.857), indicating that professionals who received the video delivery mode were 74% more likely to obtain a higher design solution quality score.

5.2.2 Self-Efficacy and Delivery Modality. Calculated self-efficacy was measured as the average response to the posttest efficacy statements, as described previously. Since the data were continuous, Welch's two-sample *t*-tests and ANOVA tests were used depending on how many groups were in the independent variable. Figure 6 shows the average calculated self-efficacy between participants that received the written versus the video delivery and between participants that were labeled high context versus low context. The results were further divided by expertise, between professionals and students. Among all groups, no statistical significance was found from the Welch's two-sample *t*-tests.

5.3 Research Question 3: Solution Quality, Self-Efficacy, and Cultural Context. The third research question posed by this study is: *How does the designer's cultural context affect their solution quality and self-efficacy?*

It was hypothesized that low-context participants would have higher solution quality because of the correlation between low-context culture and risk tolerance. Low-context participants were also hypothesized to have higher self-efficacy scores due to the value placed on individualism in low-context cultures. Self-efficacy was expected to be affected equally by cultural context among both students and professionals, as nothing in the literature review suggests that a difference would be expected.

This question was addressed by examining the relationship between solution quality and the participant's overall cultural context score, as well as between self-efficacy and the participant's overall cultural context score. In addition, the study examined the

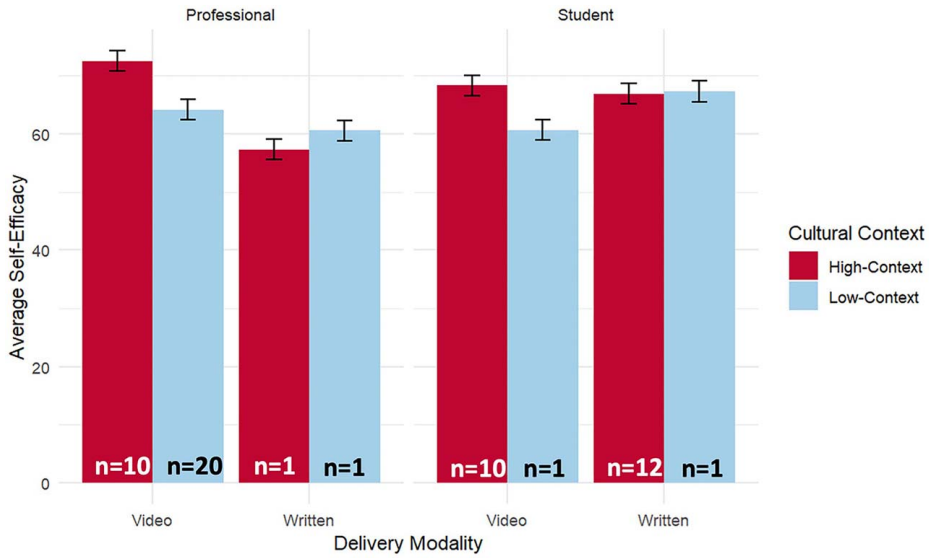

Fig. 6 Average self-efficacy by cultural context and delivery modality groups. Error bars show ±1 SE.

relationship between each of the cultural context subfactors and the two independent variables.

5.3.1 Solution Quality and Cultural Context. No significant relationship was found between overall cultural context scores and participants' solution quality scores. However, the cultural context subfactor of risk tolerance did show a significant positive correlation with solution quality among professionals.

Risk tolerance was a subfactor of the cultural context independent variable and was calculated based on participants' response to the prompt to rate their comfort "taking risks." Figure 7 shows the probability of higher design solution quality by participants' risk tolerance for professional engineers and engineering students. Using Fisher's exact test, a significant association was observed between solution quality and risk tolerance for professional participants ($p = 0.009$), whereas students' results did not show statistical significance. The odds of achieving a higher solution quality were lower for risk-averse professionals compared to risk-tolerant professionals (odds ratio = 0.760).

5.3.2 Self-Efficacy and Cultural Context. There was no significant relationship between participants' overall cultural context score and their calculated self-efficacy score. However, the cultural context social orientation subfactor did show a significant relationship to calculated self-efficacy.

Social orientation was assigned to each participant based on whether their country of culture was either individual or collective. Figure 8 shows the average combined self-efficacy score for professionals and students by social orientation. Among professional participants, a statistically significant difference was found between the calculated self-efficacy score for individualist versus collectivist social orientation ($p = 0.036$) using Welch's two-sample t-test. The results indicate that professionals who identified with cultures

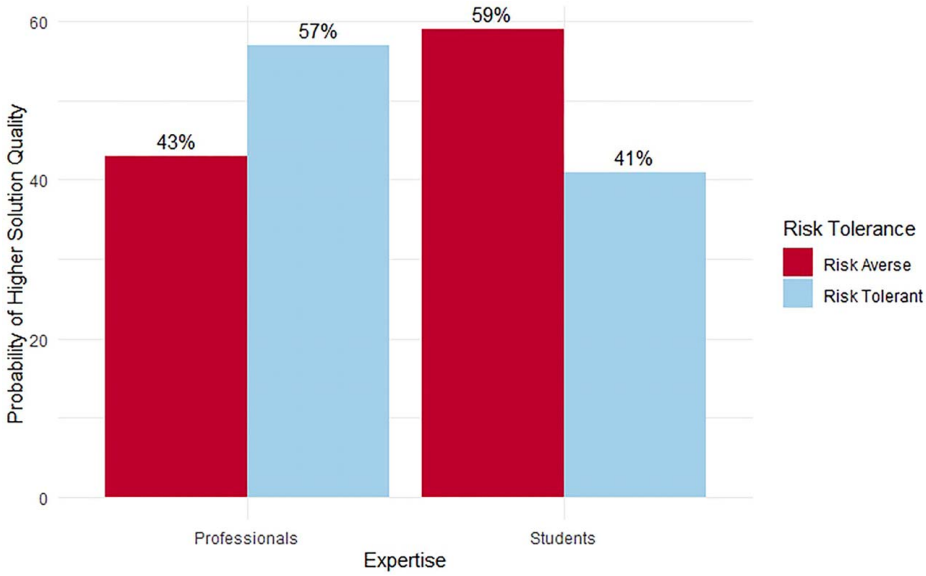

Fig. 7 Probability of higher solution quality by expertise and risk tolerance groups

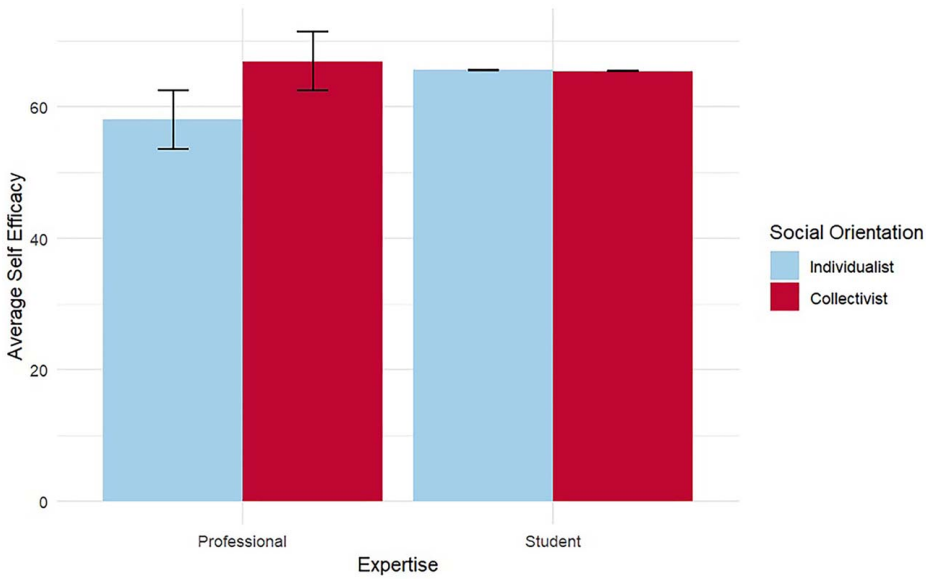

Fig. 8 Average calculated self-efficacy by social orientation and expertise groups. Error bars show ±1 SE.

that have a collective social orientation had higher calculated self-efficacy scores.

5.4 Research Question 4: Solution Quality and the Interaction of Delivery Modality and Cultural Context. The fourth research question addressed by this study is: *How do cultural context and delivery modality interact in their effects on solution quality and self-efficacy?*

Because studies have shown a positive impact from tailoring educational instruction to fit the culture of students, it was hypothesized that participants from high-context cultures who receive the video delivery mode would have higher solution quality and self-efficacy scores than participants who receive the design task in written form.

5.4.1 Solution Quality, Delivery Mode, and Cultural Context. Using Fisher's exact test, a statistically significant relationship was observed among solution quality, delivery mode, and cultural context ($p = 0.021$). Among professional participants identified as high context, those who received video delivery had 60% greater odds of achieving higher solution quality compared to those who received the written delivery mode (odds ratio = 1.5, $p = 0.012$). Students' results did not show a significant interaction among these variables.

Figure 9 compares the probability of participants obtaining a higher solution quality by delivery modality group for high-context participants.

Calculated self-efficacy was computed as the average response to the posttest self-efficacy statements. Since the data were continuous, Welch's two-sample *t*-tests and ANOVA tests were used depending on how many groups were in the independent variable. Figure 6 shows the average calculated self-efficacy between participants who received the written versus the video delivery and between participants who were labeled high context versus low context. The results were further divided by expertise, between professionals and students. As shown in Fig. 6, among all groups, no statistical significance was identified with the Welch's two-sample *t*-tests.

5.5 Additional Findings. This section discusses each independent variable that was found to be significantly associated with higher solution quality for professionals and/or students.

5.5.1 Overall Cultural Context. Figure 10 shows the probability of having a higher perceived quality rating by cultural context for professionals and students. Perceived quality rating was the participant's own rating of their solution quality on a slider bar from 0 to 100. A statistically significant relationship was observed between perceived quality rating and cultural context for student participants ($p = 0.009$). High-context students were 80% more likely to report high perceived quality ratings compared to low-context students, based on the odds ratio (odds ratio = 0.264).

5.5.2 Cultural Context Subfactor: Time Orientation. Time orientation was assigned to each participant based on whether their country of culture was flexible or monumental. Figure 11 shows the probability of having a higher perceived quality rating by time orientation for both professionals and students. Statistically significant differences were observed between perceived quality rating and time orientation for professional participants ($p = 0.017$) and student participants ($p = 0.018$). For professionals identified with monumental time orientation, the odds ratio suggested a positive association with a higher perceived quality rating (odds ratio = 1.123). For students identified with monumental time orientation, the odds ratio suggested an even stronger positive association with perceived quality rating (odds ratio = 2.550).

5.5.3 Cultural Context Subfactor: Social Orientation. Social orientation was assigned to each participant based on whether their country of culture was identified as having an individual or collective culture. Figure 12 shows the probability of having a higher perceived quality rating by social orientation for both professionals and students. Statistically significant differences were observed between perceived quality rating and social orientation both for professional participants ($p = 0.044$) and student participants ($p = 0.028$). For professionals identified with collective social orientation, the odds ratio suggested a positive association with perceived quality rating (odds ratio = 1.835). Similarly, for students identified with collective social orientation, the odds ratio suggested a positive association with perceived quality rating (odds ratio = 2.211).

6 Discussion

This section considers the results of this study in light of the literature discussed previously. The study found that delivery

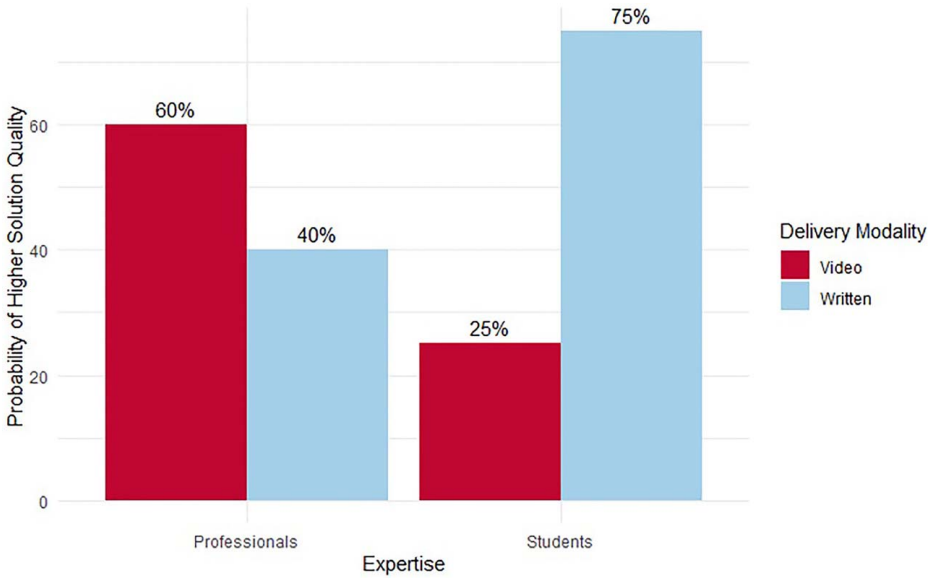

Fig. 9 Probability of higher solution quality by expertise and delivery modality groups for high-context participants

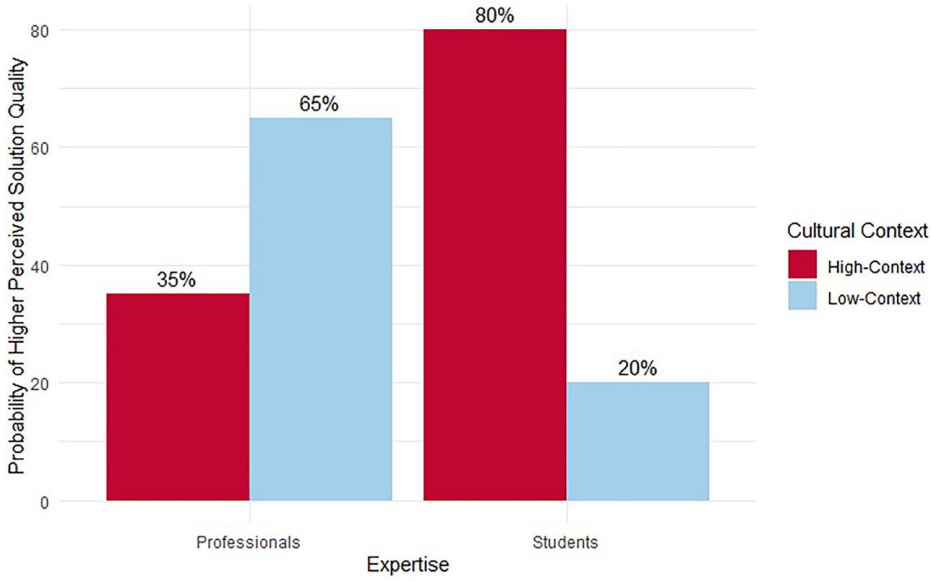

Fig. 10 Probability of higher perceived quality rating by cultural context and expertise groups

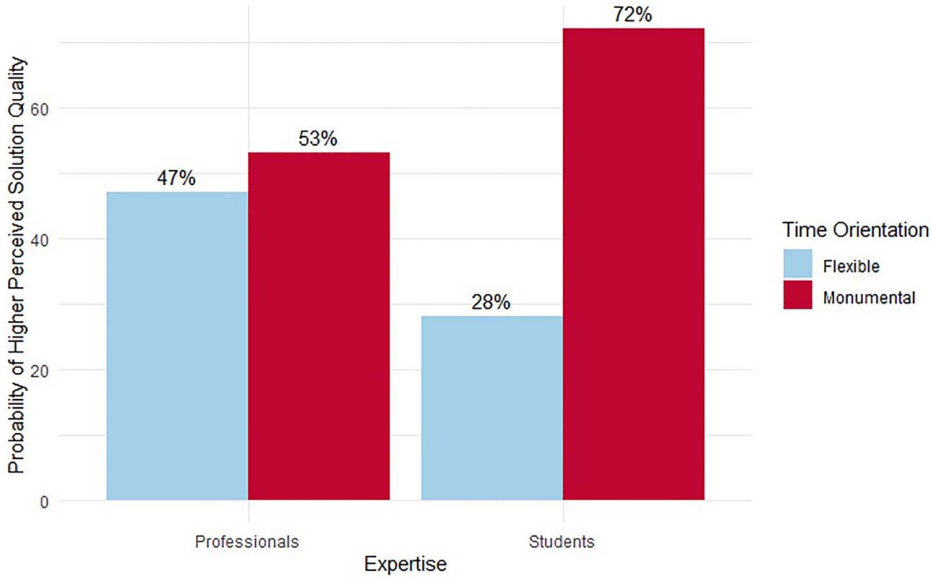

Fig. 11 Probability of higher perceived quality rating by time orientation and expertise groups

modality and cultural context (specifically risk tolerance) influenced professionals' solution quality but had no significant effect on students. Contrary to expectations, professionals were more affected by delivery modality than students. Self-efficacy in professionals was influenced by their social orientation—those with a collective orientation showed higher self-efficacy, which was unexpected since individualist cultures typically emphasize personal achievement. For students, familiarity with the design context improved self-efficacy, as expected. Surprisingly, students from high-context cultures rated their solution quality higher, and both students and professionals from collective and monumental (high-context) cultures reported higher self-efficacy, contradicting initial assumptions favoring low-context, individualist cultures. Further details and discussion of each of these findings are found in the subsections below.

6.1 Solution Quality, Self-Efficacy, and Familiarity With the Design Task. Hypothesis 1 (H1) posited that higher combined familiarity with the design task would correlate with higher solution quality and higher designer self-efficacy.

6.1.1 Solution Quality and Familiarity With the Design Task. This study found no significant association between participant familiarity with the design task (as measured by a combined score for all questions related to familiarity) and solution quality. This result does not allow one to conclusively support or reject H1, which anticipated that familiarity with the design problem would improve solution quality. Shergadwala et al. [34] found that design solution quality was better when individuals had a higher knowledge of the domain. However, Hu and Reid's [11] work on the effects of designers' contextual experience on design outcomes

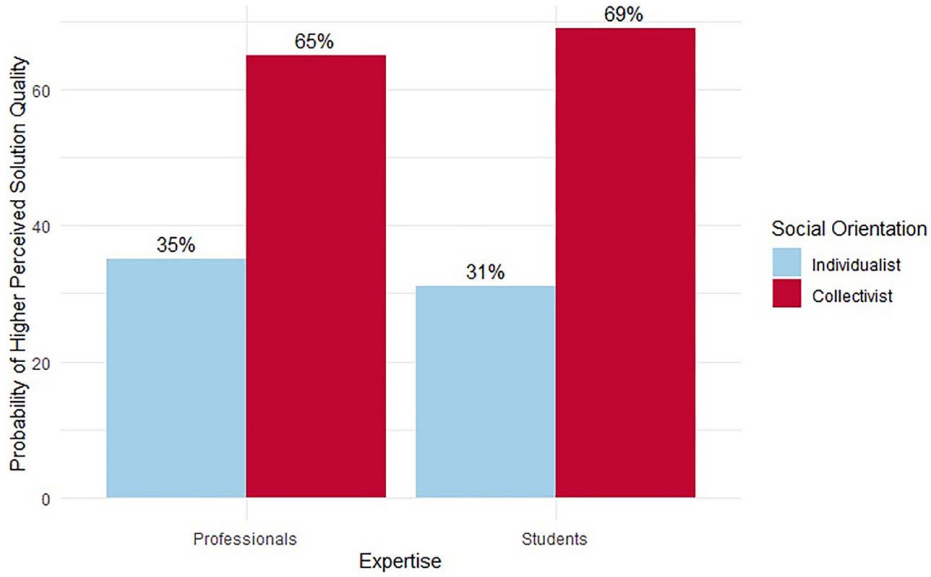

Fig. 12 Probability of higher perceived quality rating by social orientation and expertise groups

found that contextual experience with a design problem can negatively affect creativity and novelty, but positively affect the problem identification/requirements stage. These previous studies, along with the findings herein, suggest that the relationship between familiarity and design is complex and merits additional exploration. A lack of familiarity with the context of the design task could mitigate availability bias (*making judgments based on the most available information in memory* [44]), mere exposure bias (*a tendency to express a preference for stimuli following brief exposure* [44]), or anchoring bias (*using a baseline stimulus as a reference point for evaluating all other stimuli* [44]).

6.1.2 Self-Efficacy and Familiarity With the Design Task. As for the dynamic between combined familiarity and calculated self-efficacy, students who were identified as "familiar" (based on the combined familiarity score) had higher calculated self-efficacy scores. This finding provides evidence to support H1, which expected combined familiarity to correspond with higher self-efficacy. Among professionals, calculated self-efficacy was not significantly associated with combined familiarity. This could indicate that professionals' self-efficacy is less likely to be affected by their familiarity with a problem or design context because they have had more experience with unfamiliar situations and their self-efficacy is more deeply rooted as a result of their professional experience in design. The literature has shown that a lack of familiarity can be a disadvantage with respect to motivation, comprehension, recall, and cognitive load [45], which may be seen in student participants' calculated self-efficacy. Kussmaul [35] recommended that instructors focus on building students' confidence and increasing their self-efficacy by acknowledging when a design task may be situated in an unfamiliar setting. Durand et al.'s [6] results did not demonstrate that familiarity with the design problem impacted the outcome, since students were consistently equally familiar with design solutions; however, they concluded that "despite having similar familiarity and using the same method, student designers still generate a unique design fingerprint". The design fingerprint reflects the uniqueness of each person and ties into the way cultural context enables us to consider how experiences shape how we do design. This study and the related literature suggest that it may be especially important to consider potential differences in exposure to particular design problems that might impact design outcomes in educational settings to help students gain confidence in their engineering design abilities.

6.2 Solution Quality, Self-Efficacy, and Task Delivery Modality. Hypothesis 2 (H2) suggested that a more engaging delivery modality of the design task (high-context video, rather than low-context written instructions) would correlate with higher solution quality and designer self-efficacy scores.

6.2.1 Solution Quality and Task Delivery Modality. Among professionals, this study found a statistically significant positive relationship between video delivery mode and solution quality. There was no significant association between delivery modality and solution quality among students. These results support H2 for professionals, which was based on the idea that a higher solution quality would result from the video delivery because it is a more engaging format. The study also found that the video delivery mode corresponded to higher solution quality scores among professionals, regardless of familiarity and cultural context, which is consistent with Nathan's finding that interactive communication reduces cognitive demands [25]. In this study, cognitive load was reduced by means of the video delivery mode; however, using other methods and tools, such as heuristics or computer-aided design and engineering tools, can also reduce designers' cognitive load [46].

6.2.2 Self-Efficacy and Task Delivery Modality. Neither professionals' nor students' calculated self-efficacy was found to be significantly associated with the design delivery modality (video versus written). These results were inconclusive with regard to rejecting or validating H2. It is possible that an association was not found here due to the combination of factors used to calculate self-efficacy, since delivery modality was found to have a statistically significant impact on some self-efficacy subfactors.

6.3 Solution Quality, Self-Efficacy, and Designers' Cultural Context. Hypothesis 3 (H3) suggested that participants from low-context cultures will have higher solution quality scores due to the lower tolerance for risk in low-context cultures, and higher self-efficacy scores as a result of the value placed on individualism in low-context cultures.

6.3.1 Solution Quality and Cultural Context. While no significant relationship was found between the combined cultural context score and solution quality, risk tolerance (a subfactor of cultural context) did show a significant association with solution quality

Table 6 Hypotheses supported and contradicted

Hypothesis	Supported	Contradicted
H1: Higher combined familiarity will correlate to a higher solution quality and self-efficacy score.	Higher calculated self-efficacy from more familiar students.	
H2: The high context delivery modality (video) will correlate to higher solution quality, since the delivery mode is more engaging and interactive.	Higher solution quality from professionals who received the video delivery mode.	
H3: Low-context participants will have higher self-efficacy and solution quality.	Higher solution quality from risk-tolerant professionals.	Higher self-efficacy for collective professionals, higher self-efficacy for high-context students, Higher solution quality rating for monumental and collective students and professionals.
H4: Participants from a high-context culture who received the video delivery mode will correlate to higher solution quality than the high cultural context participants who received the written delivery format.	Higher solution quality from video delivery modality for high-context students and professionals.	

among professionals. Among professionals, those who identified with risk-averse cultures had statistically significantly lower solution quality scores. This result supports the underlying rationale for H3 and is supported by literature that acknowledges risk-taking as an advantageous quality in the design process [47].

6.3.2 Self-Efficacy and Cultural Context. The overall cultural context of the country that participant's most closely identified with was not found to have a significant impact on their calculated self-efficacy scores. However, the cultural context subfactor of social orientation was found to be significantly associated with self-efficacy among professionals. Professionals who were identified with a country that had a collective social orientation (characterized by the imposition of rules on behavior and low tolerance for deviation from cultural norms) had higher calculated self-efficacy. These results do not support H3, which anticipated that low-context participants (from cultures with individualistic social orientation) would have higher calculated self-efficacy. This result may indicate that social orientation is not strongly tied to cultural context, or it could indicate a lack of association between cultural context and self-efficacy. Ottingen [37] found evidence that individuals from high-context cultures are typically given feedback on their in-group performance as well as their personal performance, whereas in low-context cultures, people typically only receive personal performance feedback. So, even though people from high-context cultures tend not to view themselves separately from the group, it is possible that they have a more fully developed understanding of themselves both in-group and individually, which may explain this positive association with self-efficacy.

6.4 Solution Quality, Self-Efficacy, Cultural Context, and Delivery Modality. Hypothesis 4 (H4) suggested that participants from high-context cultures who receive the design task by video delivery mode will have higher solution quality and self-efficacy scores than people from high-context cultures who receive the design task in written format.

6.4.1 Interaction of Delivery Modality and Cultural Context on Solution Quality. Across all professionals identified as high context, those who received video delivery had higher odds of achieving higher solution quality compared to those who received the design task in writing. This finding supports hypothesis 4. A designer's level of interest and engagement impacts how much effort they put into their design. It is possible that the video was a very different method of receiving a design task than they were used to, and this novelty engaged their interest, which led to improved solution quality. This suggests that individuals from a high-context culture are likely to have better outcomes when receiving communication in a high-context modality, as previously found in the literature [22].

6.4.2 Interaction of Delivery Modality and Cultural Context on Self-Efficacy. No significant relationship was found between calculated self-efficacy based on the interaction of delivery modality and cultural context. This result did not validate H4, which anticipated that the high-context participants who received the video delivery modality would have higher calculated self-efficacy compared to high-context participants who received the design task in written mode. This result may be because subfactors used to calculate self-efficacy were too broad when combined. This possibility is supported by the fact that some significant relationships were identified when self-efficacy subfactors (e.g., perceived solution quality rating) and cultural context subfactors (e.g., time orientation and social orientation) were used to analyze the relationship between cultural context and self-efficacy.

6.5 Summary. Table 6 contains which hypotheses were supported and which were contradicted.

Results revealed that the delivery modality and the cultural context subfactor, risk tolerance, impacted professionals' solution quality, whereas none of the independent variables showed a significant impact on students' solution quality. It was unexpected that delivery modality would affect professionals' solution quality more than students, as professionals are likely exposed to more diverse forms of communication modes.

Self-efficacy was impacted by professionals' social orientation, where participants either identified with an individualist or collective culture. Social orientation was also a factor in determining a participant's cultural context, and it was anticipated that there would be a relationship, particularly due to the individualist culture's value of one's own progress rather than group progress. However, what was not expected was that those who identified with a collective culture would have higher calculated self-efficacy. Student's combined familiarity had an effect on calculated self-efficacy. This was anticipated, as familiarity with the design context has been shown to improve one's confidence. Professionals who were identified as having a collective social orientation, a subfactor of cultural context, had higher calculated self-efficacy. This was not expected, since participants from low-context cultures are identified as having an individualist social orientation, and we anticipated that low-context participants would have higher calculated self-efficacy. Students who were identified as high context reported higher perceived quality ratings compared to students who were identified as low context. We anticipated low-context participants to have higher calculated self-efficacy, so this was an unexpected result. Further affirming this result, we saw that students and professionals who were identified as monumental and collective, both subfactors of a high-context culture, showed higher calculated self-efficacy.

7 Conclusion

This study found that the solution quality and self-efficacy of professional engineers and engineering students can be impacted by cultural context and design task delivery modality. Solution quality was higher for professionals who received the video delivery mode, for risk-tolerant professionals, and for professionals identified as high context who received the video delivery mode. Calculated self-efficacy was higher for students who showed higher combined familiarity scores, and professionals who were identified as having a collective social orientation.

These findings suggest that in engineering design education, a more engaging task delivery modality, such as video, could help improve design solution quality, especially among students who identify with a high-context culture that relies on nonverbal cues. Additionally, encouraging and instructing designers to take risks in the design process could benefit the quality of their design.

With regard to self-efficacy, the findings suggest that a designer who is more familiar with the design problem, or who identifies with a collective social orientation (one that imposes rules of behavior and does not tolerate deviations from cultural norms), is likely to be more confident in their abilities and solutions.

7.1 Limitations and Future Work. Limitations in the accurate assessment of various factors were initially addressed as potential explanations for some of the findings observed in this study. Limitations in accurately assessing participants' cultural context, quantifying self-efficacy using responses to specific questions, and scoring a participant's familiarity with the design context through a series of questions could have affected the results of this study. In the future, these factors could be further refined based on additional research regarding the subfactors that went into the development of the scores.

Defining cultural context by the country with which the individual most identifies might have led to inaccuracies in defining this independent variable for each participant. An individual might identify with one country with regard to some cultural subfactors, but with a country that is categorized very differently on other subfactors. Further, since the study was conducted entirely online, with no personal interaction between the researchers and the participants, the only way the participants' communication style could be observed was through their design solution submissions. Additionally, two cultural context subfactors, time and social orientation, were based solely on the country that the participant most identified with. We know from literature [3] that the metrics used are not all encompassing of each person from that country. A future study could be designed to study the communication dynamics in a collaborative group setting and to assess each participant's cultural context through individual interviews.

Combined familiarity was a calculated variable derived from a set of questions related to the design task and the participant's prior experience with the design task. Questions were modeled after a survey used to identify participants' familiarity with two different countries' geographies [45]. This factor was not broken into subfactors, as cultural context and self-efficacy were, and refining the method to better gauge familiarity could be an area of further research.

Finally, the design task specifications might have been improved to ensure that a more consistently documented set of solutions was received. For instance, some design solutions were highly detailed and polished, whereas other submissions included only a quick brainstormed sketch. This made solution quality scores more difficult to measure against the specifications provided in the design task. Moreover, during the process of refining the quality rubric to attain a more objective scoring system, all submissions were found to meet the size requirements. Consequently, this criterion was eliminated. However, additional distinguishing factors, such as "feasibility" and "comprehensiveness," were introduced, despite the fact that the design task did not explicitly state that the solution needed to be feasible and/or comprehensive. A more detailed design task description could mitigate some of the issues that arose in scoring the solution quality. The imperfection of the Cohen's kappa interrater agreement shows subjective differences between the raters.

Overall, this study could have benefited from an increased number of participants; more extensive survey questions to identify cultural context, familiarity, and self-efficacy; in-person engagement with each participant; and permitting the use of external resources to complete the design task to more realistically emulate professional design environments.

7.2 Positionality Statement. When the manuscript for this article was drafted, one author self-identified as a US Asian and white American woman and one author self-identified as a US white American woman. The authors acknowledge that their positionality influenced this research to some extent, particularly given the cultural nature of the work.

7.3 Contributions. The work presented in this study has contributed to the literature on communication and culture in engineering design by examining the effect of the communication mode for delivery of the design problem, the designer's cultural characteristics, and the designer's familiarity with the design task on both design quality and designer self-efficacy.

Specifically, *t*his work offers a quantitative analysis of how novices and professionals respond to two methods of design problem delivery (video versus written), assessing the impact on solution quality and self-efficacy. The analysis suggests that professionals exposed to design tasks through video delivery, as well as those who embrace risk-taking, produce higher-quality design solutions. Moreover, this effect extends to high-context designers (who are used to nonverbal cues and shared understandings) who are presented with design tasks via video delivery, regardless of their familiarity with the design problem.

The finding that a designer's culture, including their communication style, social and time orientation, and tolerance for risk, is correlated with both self-efficacy and solution quality may have particular significance for engineering education, especially when conveying assignments or design tasks to a diverse student population. As the field of engineering becomes increasingly more global and diverse, educators and project managers in engineering should reassess their instructional methods, task delivery, and feedback mechanisms in light of these findings. Tailoring their delivery to the needs of the population involved will help ensure that designers are well-informed and sufficiently prepared to undertake their assigned tasks. In professional settings, an inclusive culture for individuals from diverse backgrounds and cultural contexts would include multiple communication modalities to convey information to help every team and team member achieve the highest possible quality design outcomes.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The datasets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request.

Appendix A: Pretask Questions

(1) What is your Prolific ID?
(2) In which country do you currently reside?
(3) How many years have you been working on your degree? (if Student). *
(4) Select which best describes your day-to-day activities as an engineer. (if Professional).
   (a) Mostly in office
   (b) Mostly visiting clients off-site
   (c) Mostly visiting with clients in office
   (d) Both equally
(5) Rate your level of agreement with the following statements: **
   (a) I can clearly communicate my ideas.
   (b) I am a creative person.
   (c) I can solve design problems with ease.
   (d) I can quickly brainstorm many, diverse ideas
   (e) I enjoy solving design-related problems.
(6) Rate your level of comfort with the following: **
   (a) the design process
   (b) brainstorming ideas
   (c) answering open-ended questions
   (d) taking risks
(7) I am most comfortable _____ my ideas. (Select one).
   a. Sketching
   b. Writing
   c. Speaking
(8) I am most attentive to _____ communication. (Select one).
   (a) Written (emails, letters)
   (b) Audio (voice calls, voice messages)
   (c) Face to face (in person, video calls)

*Question was provided with a drop down of numbers from 1 to 10 to allow student participants to select the number of years working on their degree.

**Question was provided with a sliding bar to allow participants to choose a percentage between 0 and 100.

Appendix B: Design Task—Written

Milk froth can be added to espresso, tea, or hot chocolate to create drinks like lattes, cappuccinos, tea lattes, and more. It differs from whipped cream, as it is lighter, airier, and contains a lower fat percentage. Froth is made when the milk is aerated either by agitation (creating bubbles) or injection of steam. Milk can be frothed hot (160 °F/65 °C) or cold (38 °F/3 °C). The best milk froth for latte art is silky and finely textured, known as microfoam. This is typically produced using a steam wand attached to an espresso machine, which can be an expensive and bulky household appliance. There are inexpensive ways to froth milk (for example, a battery-powered stick frother or a whisk), but these methods do not easily create microfoam; rather, they can add too much air to the milk, creating large bubbles that will not hold their shape. Microfoam is created when the milk is initially agitated above surface level (i.e., bubbles are created and air is incorporated into the milk) and then that air becomes distributed into finer bubbles as agitation continues below the surface of the milk, keeping excess air out.

Steamer: heats milk and injects pressurized air

Frother: aerates milk through electric or mechanical powered whisking

Design an innovative device for the home that froths milk in a short amount of time using the following specifications:

(a) The device should be compact in size, either handheld or no larger than an average smoothie blender (9 in × 11 in × 14 in/ 23 cm × 28 cm × 35 cm).
(b) The device should be low cost but durable.
(c) The device should be easy to clean.
(d) The device does not need to heat or cool the milk necessarily, milk can be preheated/cooled.

The device should create finely textured microfoam.

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