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Fostering systems thinking through engineering study abroad programs

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ABSTRACT

Engineering study abroad programs are a novel setting for students to develop systems thinking, which has primarily been taught in formal learning environments. Through a situated learning perspective, we examined the impact of two engineering-focused study abroad experiences on developing students' systems thinking skills. We conducted secondary data analysis to examine how first-year engineering students ($n = 47$) at a technical university in the United States (US) connect technical and contextual aspects of engineering in China and the UK/Ireland. The students on the China track drew connections more frequently (81% of excerpts) than those on the UK/Ireland track (49% of excerpts). Students interpreted these connections at the macrosystems level, microsystems level, personal level, and career level. Our study offers a theoretical contribution to the systems thinking framework by offering nuance to the connections students drew between contextual and technical engineering dimensions, while showing that systems thinking can be an important outcome for engineering study abroad programs.

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Systems thinking; study abroad; qualitative research; secondary data analysis

Introduction

Many scholars in engineering education emphasise the importance of helping engineering students develop integrated systems thinking skills. Systems thinking has been defined as 'a holistic approach to problem solving in which connections and interactions between constituent parts and the immediate work, stakeholder needs, broader contextual aspects, and potential impacts over time are identified and integrated into decision making' (Dugan et al. 2022). Such skills prepare engineering students to holistically solve complex problems by addressing both the contextual and technical dimensions and interrelations. For instance, many professional engineering societies, e.g. the Institute of Electrical and Electronics Engineers (IEEE 2020), the Association for Computing Machinery (ACM 2018), the American Society of Civil Engineers (ASCE 2020), the Royal Academy of Engineering (RAE), and the Biomedical Engineering Society (BMES 2021), emphasise the value of integrating social and technical considerations in the workplace through their codes of ethics. In addition, international engineering standards require engineers to consider both the technical properties of a product and the context in which it will be used (IEEE 730, ISO 9001) (IEEE 2014; ISO 2015). These standards provide guidelines to enhance quality and reliability within the engineering and

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technology sectors. By bridging the gap between technical preparation in curricula and social and contextual considerations in the workplace, we can better prepare engineering students to understand and address the complex problems faced by the world today.

Despite the increasing need for engineering students with systems thinking skills, engineering curricula tend to overemphasise the technical elements of engineering problems and solutions over the social aspects (Jonassen 2014; Leydens and Lucena 2018; Stevens et al. 2007). Further, undergraduate engineering curricula tend to focus on decontextualised, 'plug-and-chug' style problems that do not activate students' conceptual and contextual understanding (Jonassen 2014; Leydens et al. 2018). Students then struggle to transfer this academic training in solving decontextualised, well-defined problems to the workplace, where they must solve contextualised and ill-defined problems (Jonassen 2014).

In recognition of this gap, engineering educators have begun to focus on developing systems thinking skills in the classroom or workplace (Camelia, Ferris, and Behrend 2019; Dugan et al. 2022; Godfrey, Crick, and Huang 2014). However, many of these studies have taken the form of artificial scenarios that simplify real-world complexities. Engineering study abroad programs offer a potential avenue for teaching systems thinking skills in complex real-world settings. We suggest that engineering-focused study abroad programs can foster a situated understanding of engineering through different cultures, socio-politics, and economics. For example, when these programs involve visits to engineering companies, students can observe how cultural, political, and economic differences between countries impact engineering practice. Engineering education research has yet to explore study abroad as an avenue for developing systems thinking skills in undergraduate engineering students; we aim to fill this gap.

This study's purpose is to understand the impact of engineering-focused study abroad experiences on the development of systems thinking skills. We examined written reflections from two groups of first-year engineering students. These students participated in a semester-long global engineering course at their home university in the United States (US) and then travelled on a two-week study abroad program to visit engineering companies, universities, and cultural sites. One group visited China, and another group visited the United Kingdom (UK) and Ireland. We explored whether students interpreted their experiences through technical, contextual, or integrated perspectives and how their interpretations varied by the country to which they travelled. Specifically, we investigated two research questions:

1. *How often do participants draw connections between the contextual and technical dimensions in their reflections on their study abroad experiences?*
2. *In what ways do students draw connections between the contextual and technical dimensions of their study abroad experiences?*

This study bridges the gap between systems thinking research in the classroom context, and research into study abroad and global engineering outcomes. We show that study abroad offers an opportunity for situated learning of systems thinking skills that may overcome the challenges of teaching this skill in simplified classroom examples. Understanding the extent to which students demonstrate systems thinking when reflecting on engineering practice abroad may open a new avenue for scaffolding opportunities for students to develop systems thinking through both study abroad programs and other real-world experiences such as internships or undergraduate research.

Background

Scholarship in systems thinking and in international education has had limited overlap to date, especially in engineering education. In the next sections, we review literature from systems thinking and study abroad experiences as they relate to engineering education. The current systems thinking literature in engineering education research is largely on intervention-focused activities in classroom environments. With respect to study abroad, we highlight the lack of research on engineering-focused study abroad learning outcomes. To connect systems thinking with study abroad experiences, we apply situated learning theory as a way to understand students' reflections on their experiences learning about engineering practice while abroad.

Systems thinking in engineering education

As a concept, systems thinking has risen in importance across many fields for its holistic framing of complex problems. While systems thinking is not a new concept (Ackoff 1971; Senge 1990), there is no single definition of systems thinking (Dugan et al. 2024). In engineering education, scholars and educators use systems thinking to foster a 'holistic approach' to managing complex problems through 'appreciating all the interrelated dimensions' (Camelia and Ferris 2016, 1). Additionally, many systems thinking researchers in engineering education draw connections to sociotechnical thinking (Dugan et al. 2024) and sociotechnical systems (Davis et al. 2014; Dhukaram et al. 2018). Sociotechnical thinking attends to the interrelations and power dynamics between contextual and technical dimensions, which connects to many facets of systems thinking (Cech 2014; Godfrey, Crick, and Huang 2014; Leydens and Lucena 2018). Many studies in engineering education use frameworks of systems thinking to address the disconnect between how students perceive the technical and contextual dimensions of problems (Grohs et al. 2018; Mazzurco and Daniel 2020). In this study, we do not seek to disentangle or examine the different operationalizations of systems thinking (or sociotechnical thinking). Instead, we build on Dugan et al.'s (2022) definition of *comprehensive systems thinking* as a 'holistic approach to problem solving in which connections and interactions between constituent parts and the immediate work, stakeholder needs, broad context aspects, and potential impacts over time are identified and integrated into decision making' (2). We use this definition because it was developed through research on practicing engineers and engineering students (Mosyjowski et al. 2020), which aligns well with the context of our study. In line with this definition, we focus on adapting an existing systems thinking framework within engineering education (Grohs et al. 2018) to assess the systems thinking skills of engineering students who have experienced engineering practices outside of their home institution in the US.

In engineering education, most of the efforts to teach systems thinking to engineering students have focused on classroom interventions and assessment instruments. These interventions have consisted of revisions to existing engineering courses with systems approaches (Andrade and Tomblin 2019; Claussen and Smith 2019; Özkan and Andrews 2022), while others have created new courses, such as 'Drones for Good' (Hoople and Choi-Fitzpatrick 2020) and Humanities-Informed Engineering Projects (Davis et al. 2021). In this study, we use a systems thinking framework to examine the insights of students who are reflecting on two weeks of international experiential learning. We assess *whether* and *how* they draw connections between their contextual insights and their technical insights.

Systems thinking in situated learning programs and experiences

Relatively few studies consider systems thinking or related skills as learning outcomes from study abroad experiences or industry learning experiences. Scholars have cited systems thinking as beneficial for students in internships (Ercan and Caplin 2017; Laguador, Chavez-Prinsipe, and De Castro 2020) but do not examine notions of students' systems or contextual thinking development during industry experiences. Alexis et al. (2017) used a global engineering framework to analyze post-research-abroad interviews with STEM undergraduate students and found that they rarely mentioned systems thinking skills compared to communication skills, multidisciplinary teamwork skills, and social responsibility. Similarly, Neeley (2014) asked engineering students to self-assess their learning on a range of intercultural and analytical skills after participation in a short-term study abroad program. This study also found that students reported greater learning of intercultural outcomes compared to analytical skills such as systems thinking. Study abroad programs focused on sustainability often mention systems thinking as a desired learning outcome (e.g. Burian and Romero 2012), but there are few reports of assessment or research related to these programs. One exception is a photoelicitation study by Berdanier, Tang, and Cox (2018) that explored ethical reflections of graduate students after a sustainability-focused study abroad program, finding that the students' conceptions of sustainability included intersections between social, economic, and environmental factors.

Humanitarian engineering programs are also more likely to explore outcomes related to systems thinking (e.g. Mazzurco and Daniel 2020) and may include global components such as collaborating with a global partner or travelling abroad. For example, Smith et al. (2021) assessed the related skill of sociotechnical thinking in a fieldwork program in humanitarian engineering. These authors specifically sought to understand the complexity of sociotechnical thinking demonstrated by students in the program over time, identifying four levels to characterise this complexity from low (recognition that engineering has both social and technical dimensions) to high (recognition that the social and technical dimensions of engineering imply and co-constitute each other). Our project builds on this method by exploring the different ways that students integrate social and technical thinking, though we focused on different forms of integration rather than different levels. Our work also brings a new perspective by exploring systems thinking development in a short-term study abroad program that is *not* specifically focused on sustainability or humanitarian engineering topics.

Learning outcomes from study abroad experiences

Much of the research of study abroad experiences has focused on intercultural learning outcomes (Davis and Knight 2023; Salisbury 2015). This research has led to an understanding of what students do and do not learn abroad in terms of intercultural competence (Vande Berg and Paige 2012) and what types of experiences and interventions can support students' intercultural learning (Lou and Bosley 2012; Vande Berg, Connor-Linton, and Paige 2009). However, researchers in the field have begun to call for a broader focus on different learning outcomes and assessment methods within study abroad research (Deardorff 2015; Salisbury 2012, 2015; Streitwieser and Light 2017; Wong 2015).

Within engineering education, several studies have demonstrated that engineering students can develop intercultural competence through participation in study abroad, research abroad, and in-class global activities (Alves 2018; Ball et al. 2012; Berka et al. 2017; Davis 2020; Davis and Knight 2018, 2021; Davis et al. 2018; Downey et al. 2006; Jesiek, Haller, and Thompson 2014a; Jesiek et al. 2014b; Joshi et al. 2021; Knight et al. 2019; Levonisova et al. 2015). However, intercultural competence development alone does not account for the unique skills required for global engineering work. Those skills have been collectively termed *global engineering competency* (GEC; Jesiek, Haller, and Thompson 2014a; Jesiek et al. 2014b; Jesiek et al. 2020). GEC requires an integration of intercultural competence with engineering technical skills; in a sense, it can be viewed as a specific type of systems thinking. Thus far, little work has focused on the development processes for GEC. Some studies have suggested that even students with notable intercultural competence development may fail to connect these skills to their engineering work (Davis 2020; Davis and Knight 2021). Our study explores one type of international experience that may support the development of GEC and provides evidence in support of integrated student learning in engineering.

Study abroad as a highly situated learning environment

Students can experience a diversity of highly situated learning environments – from internships to design projects to study abroad programs. A situated perspective of learning suggests that knowledge is distributed across people and their environment (Greeno, Collins, and Resnick 1996), which can be useful for examining the plurality of student learnings during study abroad. According to

Johri, 'a central aim of the situated perspective is to understand learning as situated in a complex web of social organisation rather than as a shift in mental structures of a learner' (Johri and Olds 2011, 160). In a study abroad experience, students learn in unexpected ways, which make situated learning a helpful theoretical lens. Situated learning has its roots in communities of practice through the concept of 'legitimate peripheral participation' (Lave and Wenger 1991). Students learn by participating in the authentic practices of a community – for instance, peripherally participating in cross-cultural engineering practice on a study abroad experience for engineering students. Through a community of practice, students move from the peripheral to full participation by engaging in authentic (rather than abstract) engineering settings (Newstetter and Svinicki 2014; Paretti 2008). By examining student learning on study abroad experiences, we can study how students engage with different engineering communities of practice as they exist across different cultural, social, and political contexts.

In this study, students have multiple opportunities to engage with international engineering professional practices, which can cultivate learning that is different from formal classroom learning. We draw from tenets of situated learning theory to inform our analysis of engineering student learning as they reflect on their study abroad experiences. The reflections of the students in this study reflect a web of contextual and technical concepts that they organise in different ways. As students engage in different cultural and material situations, they draw connections rooted in knowledge from their different lived experiences. Although all learning sits within a specific context (i.e. classroom, home, etc.), an engineering-focused study abroad provides an opportunity to focus on situated student learning in different social, cultural, and material contexts. Through this perspective, we can examine students' knowledge production or, in our case, student learning, as constant construction and reinterpretation within and of social contexts (Clancey 2009). A situated learning perspective is the underlying paradigm through which we use our theoretical framework, described below, in our analysis of student learning.

Theoretical framework: dimensions of systems thinking

The data analysis for this study was guided by the Dimensions of Systems Thinking framework developed by Grohs et al. (2018) that describes the integration of technical and contextual aspects in

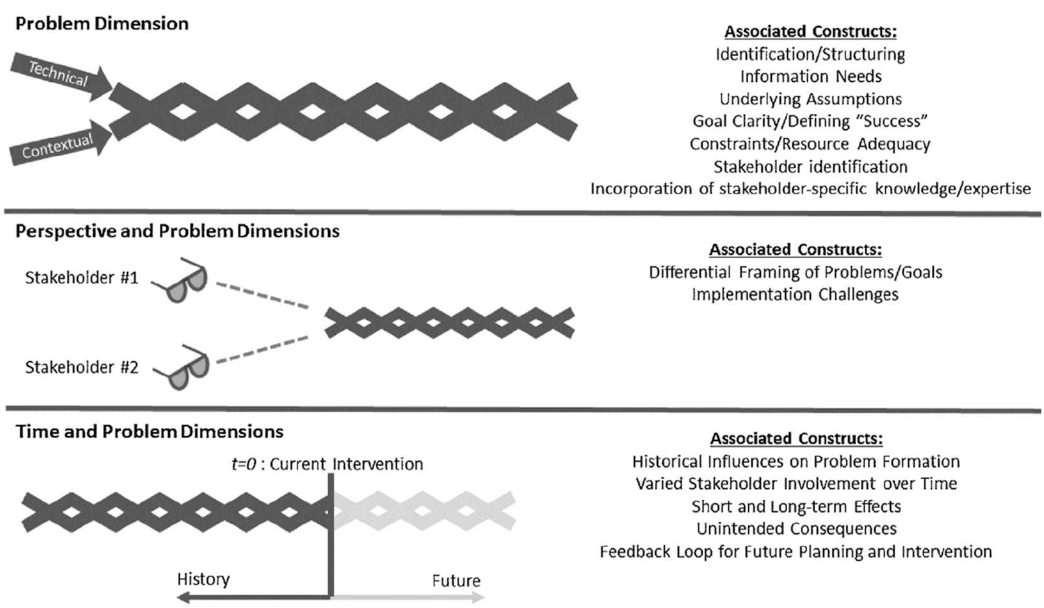

Figure 1. Dimensions of Systems Thinking Framework (Grohs et al. 2018).

engineering (Figure 1). The framework is taught as part of the class the students took before studying abroad, although it did not directly inform the design of the travel portion of the program or the data collection procedures. The framework was developed based on systems thinking literature from multiple disciplines. It integrates the three dimensions of problem, perspective, and time, as shown in Figure 1.

(1) The *problem dimension* focuses on the intertwining of technical and contextual elements in a complex problem. Grohs et al. (2018) define technical elements as 'objects, tools, knowledge, and processes employed to transform inputs (e.g. problems and resources) to outputs (e.g. solutions and consequences)' (112). Contextual elements are defined as 'the environment in which these technical elements are embedded, including social, cultural, political, legal, ecological, and economic features' (Grohs et al. 2018, 112).
(2) The *perspective dimension* describes how diverse stakeholders, with their varied values, beliefs, and experiences, can influence the definition of problems and development of solutions.
(3) The *time dimension* refers to the past and future of a specific problem, including previously attempted solutions and potential long-term consequences (Grohs et al. 2018).

Grohs and colleagues provide a scenario-based assessment tool with scoring rubrics in their paper, which is intended to assess systems thinking competency for problem definition and solution (2018). Our project did not specifically examine students' ability to define or solve problems, but we found that the rubrics included in the paper provided useful guidance for assessing students' systems thinking based on qualitative data. Thus, in this study we adopted the concepts of technical and contextual elements defined in the Dimensions of Systems Thinking Framework and their operationalisation in the provided scoring rubrics to inform our coding process as we analyzed students' reflections from their study abroad experience.

We provide specific details on how we adapted the framework for our study in the methods section and Table 2, where we show how each dimension is defined based on the student reflections. Past studies have used this framework more as a scenario-based assessment. Amelink et al. (2024) used the tool to compare student thinking in STEM and outside of STEM, Davis et al. (2021) examined how engineering students responded after having humanities education, and Liu (2023) focused their assessment on students in a climate change course. In these studies, the researchers examine student responses to a specific scenario and then quantitatively assess responses across the dimensions. In this study, we take the study abroad experience as the scenario and examine the broad patterns students exhibit quantitatively, as well as the qualitative nuance in their experience reflections through the frame of contextual and technical dimensions.

Program description

The RSAP is a program for first-year engineering students that teaches students about global engineering practices. The program is housed at a research-focused institution in the mid-Atlantic region of the United States. Participants take a spring semester (January to May) course and then complete a two-week study abroad experience with 20–30 fellow classmates (a 'track'). The course covers global engineering problems, global collaboration, and skills for interacting in global professional settings through a combination of guest speakers, interactive class activities, and group projects. The abroad portion of the program occurs in different locations; in 2019, the program ran tracks in Australia/New Zealand, Chile/Argentina, China, Europe (Germany, Italy, Switzerland, and Austria), Spain/Morocco, and UK/Ireland. Each of these tracks is planned and coordinated by a third-party study abroad provider, in consultation with the RSAP team, and includes visits to engineering companies, universities, and local cultural sites. Students rank their track preferences in their program application and are placed into tracks based on the quality of their applications. Relevant to this paper, the UK/Ireland and China tracks were neither the most popular nor the least

Table 2. A Priori Codes for Technical and Contextual Elements from Grohs et al. (2018).

Original Definition from Grohs et al.	Adapted Definition (based on our data)
Technical Elements of Systems Thinking	
Knowledge/information regarding scientific developments that an organisation/entity can acquire in order to produce goods and services	**Knowledge or information regarding scientific developments** – specific scientific or technological developments. Does not include vague statements about 'technology.'
Physical objects or artifacts (e.g. equipment, tools, products, input/raw materials – including nature and natural resources, by-products) used in the production/delivery of goods and services	**Physical objects or artifacts** – equipment, tools, products, raw materials. This includes works of engineering, 'feats' of engineering, buildings etc.
Knowledge needed to develop and apply equipment, tools, and methods to produce/deliver goods and services (e.g. how to assemble an automobile, design a software program, operate a missile tracking system)	*This technical element did not occur in our data*
Activities or processes that comprise the methods of production/delivery of goods and services	**Activities or processes** – approaches used to produce goods and services. This includes collaboration, leadership, and teamwork
Contextual Elements of Systems Thinking	
Economic – composed of labour markers, financial markets, markets for goods and services, financial capabilities of stakeholders (e.g. salary/income potential of end users)	**Economic** – labour, markets, salaries, and income
Political – distribution and concentration of power; nature of political system (e.g. democratic vs. autocratic) applicable in the area/context of the community/organisation	*We combined the Political and Legal categories into one because student comments on these topics were interconnected.* **Political** – the political system (including laws) and distribution of power in the community
Legal – defined by the constitutions and laws of the nations in which the organisation conducts its business, as well as the legal practices in each of these domains.	
Social – associated with class structure, demographics, mobility patterns, life styles, and traditional social institutions including educational systems, religious practices, trades, and professions.	**Social** – class structure, demographics, lifestyles, and professions
Cultural – issues such as history, traditions, expectations for behaviour, and the values of the society or societies in which the organisation operates.	**Cultural** – relevant history, traditions, behavioural expectations, and values

popular tracks in the 2019 RSAP program applications. More details about the program can be found in previous papers (Knight et al. 2019; Davis and Knight 2021).

Relevant to our research questions, one of the topics covered in the Global Engineering Practice course is systems thinking. Early in the semester, students are presented with the Dimensions of Systems Thinking framework from Grohs et al. (2018), described earlier in the Theoretical Framework section. In the classroom, small groups of students analyze a case study and then the class discusses how each of the dimensions of systems thinking can help interpret that case study. Students are then placed into teams of three to work on a project together over several weeks where they identify an engineering-related challenge in an assigned country within the region of the world they will visit during their time abroad. The students must analyze this challenge using the provided systems thinking framework and create a poster to summarise their analysis. The project culminates in a poster session where the students share their project and learn about the projects completed by the other teams.

Methods

In this study, we explore how students interpret the social, cultural, economic, and political contexts of engineering work that they learn about during a study abroad experience. We compare student learning across two study abroad destinations: (1) China and (2) the United Kingdom and Ireland. To address our research questions, we conducted a secondary data analysis (SDA) on qualitative reflective journal reflections. The reflections were written by students participating in the 2019 RSAP program during the two weeks that they were abroad in these two locations. In this study, we adopt a constructivist worldview to make meaning from student experiences (Patton 2002). We employed several rounds of qualitative coding to address two research questions:

1. How often do participants draw connections between the contextual and technical dimensions in their reflections on their study abroad experiences?
2. In what ways do students draw connections between the contextual and technical dimensions of their study abroad experiences?

Track selection

For this study, we chose to focus on students who participated in two of the international tracks from the 2019 RSAP cohort and analyzed all the journals for students on these tracks. We chose this sampling approach because an initial reading of student reflections suggested that there may be differences in students' demonstrated systems thinking skills across tracks. This observation was supported by prior research on other learning outcomes from this and similar programs, which had suggested that some learning outcomes differ based on cultural distance of the location that students travelled to from United States culture ([Davis and Knight 2018; Davis 2020; Davis and Knight 2021). Cultural distance describes how different two cultures are, often measured using the six dimensions in Hofstede's model of national culture (Hofstede 1983; Hofstede, Hofstede, and Minkov 2010). To calculate cultural distance, we used the formula provided by Yeganeh (2011), which has been used in previous studies (e.g. Davis and Knight 2021), and the data from the Hofstede Insights website (Hofstede Insights 2018). For the purposes of this study, we chose two tracks at the extreme ends of the cultural distance spectrum (i.e. very high distance and very low distance) so that any differences would be particularly evident in our analysis. Although language differences are not accounted for in the cultural distance score, it is worth noting that we also have one track where the primary language is English and one where it is not, as communicating across a language barrier can be a significant experience for students (Davis and Knight 2018). Short descriptions of each of these tracks, one to China and one to the UK/Ireland, are provided below for additional context. We acknowledge that the curation of both tracks is not necessarily representative of each country's broad cultural and political spectrum. These tracks were organised by a third-party company that employs US citizens who have spent extended time and/or reside in China and the UK/Ireland.

Context for China trip

The 2019 China track had 25 students and three track leaders (one faculty member and two PhD students). The China track travelled to four different cities in China (Beijing, Jinan, Shanghai, Suzhou). Students visited companies including Pratt & Whitney, United Technologies, Canature Environmental Industrial Park, and Pansoft as well as universities including Shanghai University of Engineering Science and Beijing Normal University. The program also visited TusPark, a world-famous Science Park often referred to as China's Silicon Valley as it houses many of China's most promising high-tech startups. The China track included several cultural visits to places such as the National Museum of China, the Bird Nest and Water Cube of the 2008 Olympic Park, the Great Wall of China, Tiananmen Square, and the Forbidden City.

Context for UK/Ireland trip

The 2019 UK/Ireland track had 31 students and three track leaders (two faculty members and one PhD student). The UK/Ireland track visited London, Winchester, and Nottingham in England and Dublin and Galway in Ireland. Students visited companies including Atkins, ARUP, Mini Cooper, Foodcloud, and Boston Scientific as well as universities including Oxford in England and Trinity College in Dublin. The program additionally provided engineering-focused tours of both Tower

Bridge and the London Underground. The UK/Ireland track included several cultural visits to places such as Big Ben, Peak District National Park, St. Patrick's Cathedral, and the Cliffs of Moher.

Participant profile

The participants in this study were undergraduate engineering students who travelled on the China and UK/Ireland RSAP tracks in 2019. The majority of participants were 'rising sophomores', *i.e.* students who have completed their first year of engineering coursework (out of four total years). The UK/Ireland track had several students who were 'transfer students', *i.e.* students who completed some general coursework at a preparatory institution (community college) and then enrolled in our institution for more rigorous engineering training. Of the 25 students on the China track and 31 students on the UK/Ireland track, 23 of the former and 24 of the latter provided consent for participation in this study. Thus, reflections from a total of 47 students across both tracks were analyzed in this study. Table 1 provides demographic information for the participants in our study. The study was approved by Institutional Review Board (Project #11-098).

Data collection

While abroad, students were required to keep a reflective journal. Students wrote a total of four journal entries during their two weeks abroad, each entry a few paragraphs long. Rather than providing specific prompts for each experience, program leaders developed a general reflection template with questions to help students reflect on different types of situations. This reflection template was developed based on literature about reflection in study abroad (e.g. Kortegast and Boisfontaine 2015; Ogden 2006). The assignment instructions asked students to think of specific meaningful experiences that had occurred since their last journal entry and use the reflection template to help them make connections, explore ideas, challenge their beliefs, recognise patterns, or identify applications of things they had learned. The reflection instructions and reflection template are provided in Appendix 1. Notably, the prompts were not focused on systems thinking or contextual dimensions in engineering.

Table 1. Participant demographic information ($n = 47$).

	China Track ($n = 23$)		UK/Ireland Track ($n = 24$)	
Gender	Men = 74%	Women = 26%	Men = 71%	Women = 29%
Nationality	US = 100%		US = 96% Vietnamese = 4%	
Race/Ethnicity	Asian = 9% White = 65% Two or More Races = 17% Not reported = 9%		Asian = 8% Black/African American = 4% Hispanic/Latinx = 4% White = 71% Two or More Races = 13%	
Academic Year	Rising sophomore = 100%		Rising sophomore = 83% (20 students) Transfer student from community college = 17% (4 students)	
Intended engineering program	Aerospace = 13% Biomedical = 8% Chemical = 9% Civil & environmental = 4% Computer science = 4% Computer = 4% General (undecided) = 22% Industrial & systems = 13% Material science = 9% Mechanical = 13%		Aerospace = 25% Biomedical = 4% Chemical = 8% Civil & environmental = 4% Computer science = 8% Electrical = 8% General (undecided) = 13% Industrial & systems = 4% Mechanical = 25%	

Data analysis

The journals students kept in the RSAP were primarily a pedagogical tool to support student learning abroad but were designed so they could also support program assessment and research. The original research intent was to investigate students' intercultural learning by understanding how they made connections, explored ideas, and challenged their beliefs as they reflected on their experiences abroad. Because we chose to analyze this data set for a different purpose than that for which it was collected, our study is a secondary data analysis (SDA). Recent scholarship in engineering education has called for the use of SDA on qualitative data sets, as the practice is far more common among quantitative data sets (Walther, Sochacka, and Pawley 2016). In our case, our interest in analyzing the journals to understand students' systems thinking developed while reviewing students' journal entries. In line with engineering education researchers who use SDA, we emphasise SDA's ability to help researchers fully immerse themselves in the complex richness of qualitative data sets rather than moving on to the next data set (Johri, Madhavan, and Vorvorneanu 2016; Paretti et al. 2023). Our research team read through a sample of the journals from across all RSAP tracks and found that students were interpreting the social, cultural, and political contexts of engineering work that they encountered while abroad. Our observations and group discussions led us to frame our current research questions and develop the following analysis approach, depicted in Table 2.

To address our research questions, we conducted multiple rounds of both a priori and thematic coding. First, we identified all cases where any technical content was discussed in the student journals. We extracted these excerpts following the definitions from the theoretical framework, as shown in the top part of Table 2. We used these excerpts from the journals as the focus of our analysis because, although there was a lot of contextual content (e.g. cultural observations) in the journals, much of it was disconnected from technical content. Next, we used the technical and contextual elements from our theoretical model as our set of a priori codes to analyze the excerpts (these codes are described in Table 2). Each excerpt was coded by two research team members and the team negotiated any differences to reach consensus. During this phase of analysis, the whole research team met regularly to discuss the coding process, review excerpts together, and refine our operationalisation of each element from the theoretical framework (shown in the right column of Table 2). The resulting data sufficed to answer our first research question, about the frequency at which students connect contextual and technical dimensions in their reflections. We then conducted a second round of analysis to answer the second research question about how students integrate technical and contextual connections. In this analysis, we open coded the excerpts that were identified through the first round of coding as having both technical and contextual elements present to identify how these elements were integrated. As a result of this second round of coding and discussions amongst the research team, we identified four codes describing types of integration (see Table 3 in Results section). We then conducted a final round of coding where we applied these four integration codes to the data. Again, throughout this process at least two team members reviewed the coding for each excerpt and negotiated to consensus as needed.

In Table 2, the left column shows the definitions provided by Grohs et al. (2018) for the technical and contextual elements within their Dimensions of Systems Thinking framework. The right column shows the clarifications and adaptations we made as we operationalised this framework within our data. We made two adjustments to the framework based on our initial round of data analysis: we removed one of the technical elements, *Knowledge*, that did not appear in our data; and we merged two contextual elements that we could not distinguish in the journals (legal and political). We found that participants did not explicitly mention the legal system in either country and that any topic that could be classified as legal (e.g. regulations, mergers) was discussed in a way that more clearly aligned with the political element (e.g. corporate mergers prompted by political forces).

Table 3. Codes Describing Students' Approaches to Technical and Contextual Integration.

Code	Definition	Example Quote
Macro-system interpretation	Focuses on national-level systems such as government, international relations, or national culture.	'This company epitomized Chinese values which I had learned, including the value of public perception, or 'saving face,' and the respect people have towards their home country despite its flaws. The company revolved entirely around the fact that Chinese tap water systems have poor quality, but there was not a single element of disrespect towards that fact. Every piece of the company maintained the greatest dignity with white plastic-clad exteriors and visuals or purity and health around every corner. The facility reminded me of a Tesla or Apple store more than a water filtration company. It was almost a cult of personality that followed these water filtration devices, and I couldn't stop listening to it.' [China 27] [Codes: Physical objects, Activities/Processes + Cultural]
Micro-system interpretation	Focuses on individual companies, business considerations, company stakeholders, design constraints	'This experience got me thinking about what things engineers considered when designing something. There were many factors that probably went into designing the bridge, such as aesthetic, constructability, and max load, but I wonder what things were prioritized over others. I would imagine that the top priority would be cost, but since this bridge was designed for the middle of London maybe aesthetic was the top priority. I would really like to know how they made their decision-making process.' [UK/Ireland 4] [Codes: Activities/Processes + Cultural]
Personal and Career	Relates to personal experiences or future career ideas and directions	'What I found most fascinating was how quickly and easily the tunnels have been repurposed during their long lifetime. Something to take away from this that I can apply moving forward is when designing or building something that is intended to last a long time, I should try and make it easy to repurpose the item to be for something else. Making a product that can easily be changed into something else or have multiple uses is not only more valuable to the customers but it is something that is becoming more desirable in our world today as we look to do more with less.' [UK/Ireland 5] [Codes: Physical objects, Activities/Processes + Social]
Observation without interpretation	Describes observations without relating observance to themself, micro, or macro aspects	'Around the corner from the wall of goals was their city management exhibition. The centerpiece was a wall of TVs playing live footage from street cameras all over Shanghai. From the outside you can see the cameras and you know that they are there but it does not seem present in day-to-day life. However, everything that is done in the city is recorded. On the TVs we could clearly make out people's faces walking down the sidewalk. It was kind of scary that this was just feeds from 20 or so cameras that we were watching whereas there seemed to be five to ten cameras on every street. I wish that I could openly talk to someone in the Chinese government about what they are doing with the cameras and surveillance.' [China 35] [Codes: Physical Objects + Political]

Positionality of research team

In positioning this study as an SDA, the authors' relationship to the data is an important quality consideration (Walther, Sochacka, and Kellam 2013). Author Murzi was responsible for teaching and overseeing the semester course, study abroad program, and was also the lead investigator for data collection and research related to the program from 2019 to 2023. Author K. Davis worked closely with RSAP from 2015 to 2020 as a graduate research assistant. Authors, Özkan, J. Davis, and Deters have all taught at least one recitation section for the program and travelled on at least one track. All five authors have been involved in other research projects related to RSAP. Additionally, two authors have travelled on the China track (one travelled on this track in 2019), and two authors have travelled on the UK/Ireland track (neither for the 2019 program). Although this study is an SDA, the authors have a deep familiarity with the data set and the broader program that makes them well-positioned to conduct this SDA.

Limitations

This study has several limitations. Our study shares the limitation of all SDA, namely, that the data were not originally collected for this purpose. Although systems thinking was taught as part of one of the course projects, it was not explicitly included in the journal assignment or reflection template. Further, the program was not designed with systems thinking development as an intended outcome. For example, the program itinerary was not designed with this outcome in mind and track leaders were not prompted to encourage or support students in developing their systems thinking skills (as they were for intercultural competence). As a result, we expect to obtain a more organic perspective on the phenomenon of interest than what might emerge from a targeted research study.

Two aspects of RSAP may affect our results. First, there are differences between the studied populations. The students on the UK/Ireland track tended to have less international travel experience than the students on the China track. Second, the leaders on each track are different faculty with different positionalities, motivations, and expectations (Özkan et al. 2020). Both differences could have influenced how students experienced their respective study abroad program.

Findings

Students on both tracks reflected on the technical aspects of their experience in similar frequencies across the three technical categories. However, we found that students on the China track discussed the contextual aspects of engineering work much more frequently. In general, these students were more likely to include contextual information alongside their discussions of technical engineering topics — 81% of the China track's technical excerpts included at least one contextual aspect, compared to only 49% of excerpts for the UK/Ireland track. Students on the China track were more likely to discuss political, economic, and (to a lesser extent) social influences on engineering projects than students on the UK/Ireland track.

Students discussed the technical and contextual dimensions together in a range of ways. Some provided deep reflections in which the contextual and technical dimensions were difficult to separate (Jesiek et al. 2019), while others shared more combinatory reflections. Students most often integrated the technical dimension of 'activities or processes' with one or more contextual dimensions. We also found that students most frequently connected the cultural dimension with technical dimensions, followed by economic and political dimensions.

> RQ1: How often do participants draw connections between the contextual and technical dimensions in their reflections on their study abroad experiences?

The first step in our analysis was to understand how often participants drew connections between the technical and contextual dimensions of engineering in a single excerpt (RQ1). Figure 2 depicts the frequency pattern across both destinations, showing how often the technical dimensions on the left were connected to the contextual dimensions in the centre, with differentiation by track on the right.

As depicted in the figure, students most often integrated the technical dimension of 'activities or processes' with one or more contextual dimensions (74%). We also found that students most

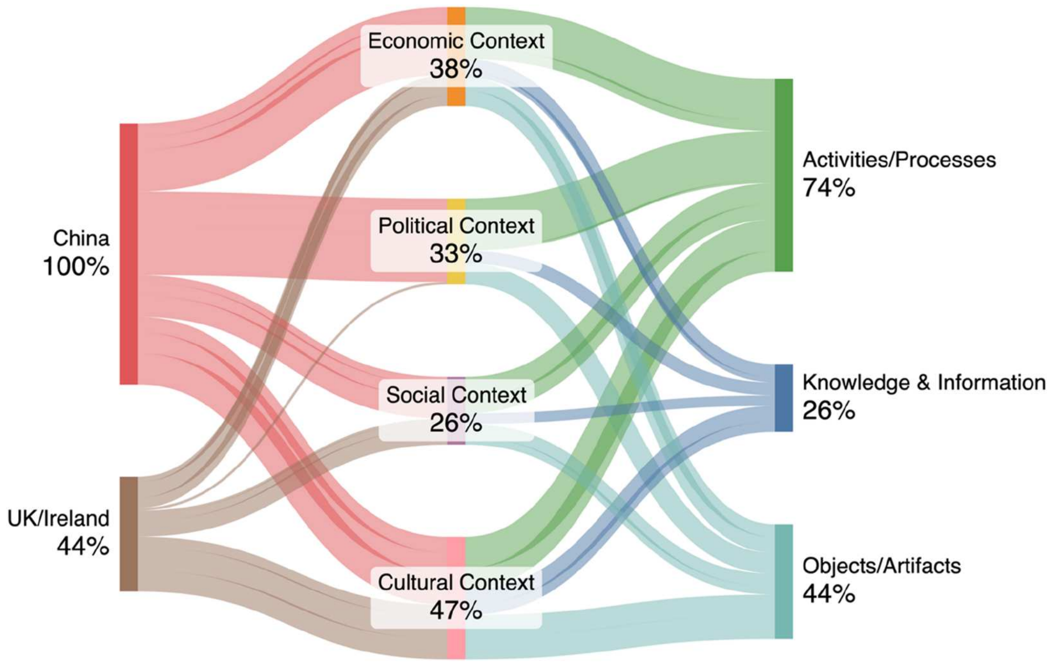

Figure 2. Sankey Diagram showing the percentage of journal excerpts where students integrated social and technical dimensions across each track. Total student journals for both tracks = 47. Number of journal excerpts for China = 116 and UK/Ireland = 82.

frequently connected the cultural dimension with technical dimensions (47%), followed by economic (38%) and political dimensions (33%).

We also see more connections on the China track than on the UK/Ireland track. Every journal excerpt from the China track drew connections between technical and contextual dimensions (100%), whereas only 44% of these connections were made on the UK/Ireland track. We also see that few UK/Ireland excerpts focused on political dimensions (1%), whereas this dimension had the most excerpts in the China track (32%). This Sankey diagram is based on Tables A1–A3 in Appendix 2.

> RQ2: In what ways do students draw connections between the contextual and technical dimensions of their study abroad experiences?

After we analyzed how often students integrated the contextual and technical dimensions, we examined differences in the ways in which students made these connections and investigated this variability (RQ2). Through an iterative inductive coding process, we developed a codebook describing four approaches to integration demonstrated by the students in their journals: macro, micro, career/personal, and observation without interpretation. These codes, their definitions, and example quotes are listed in Table 3.

Table 4 shows a frequency percentage of each code across countries. Interestingly, we see that students on the China track had far more macro-system interpretations (61%) than the students on the UK/Ireland track (24%). For micro-system interpretations, the reverse is true: students on

Table 4. Percentage of excerpts with each integration approach by destination.

	Macro	Micro	Personal & Career	Observation without Interpretation	No Contextual Code for Integration
China	61%	3%	13%	4%	18%
UK/Ireland	24%	22%	22%	7%	24%

the UK/Ireland track had more micro interpretations (22%) than those on the China track (3%). Students on the UK/Ireland track also had more personal and career interpretations than those on the China track (22% vs. 13%, respectively).

In addition to the frequency analysis, we were interested in the *types* of experiences that students were interpreting. In the following section, we focus on the themes apparent across each interpretation. This section is organised by macro-system, micro-system, and personal/career interpretations. We omit the theme of observation because these reflections had no broader interpretation: students simply recorded their experience without specific interpretations beyond a description of events. The last row in Table 3 shows an example of this code.

Macro-system interpretation (China 61%; UK/Ireland 24%)

In the macro system interpretation, students reflect on national-level systems such as the government, international relations, or national culture. Students on the China track reflected more at the macro-level than students on the UK/Ireland track, and their macro-level reflections clustered around topics based on their experiences at company visits. In China, students brought up worker safety, gender, and automation, while in the UK/Ireland, students brought up the environment and engineering as a field. In this section, we describe the students' experiences and what incidents led to this type of interpretation.

Worker safety

Many students on the China track noted macro interpretations around the topic of worker safety. For one student, seeing a welder without a welding mask led them to note different safety standards across countries:

> The elevator parts company was really intriguing to me because of their safety standards, or lack thereof. There were dudes just standing there, right in front of us, welding without welding masks or respirators on. They didn't offer us masks either! That's a huge no-no! Welding, or watching someone weld is like looking at the sun! You could permanently damage your eyesight at any moment! And it was part of the tour! They weren't even trying to hide that this was going on. I guess that's just how bad safety standards are in some Chinese factories? I wonder if American factories are ever that bad? [China 37] [Codes: Physical Objects/Artifacts, Activities/Processes + Political].

This student drew a judgment based on their observation to interpret safety standards in 'some Chinese factories' which he then followed with a question of safety practice in the US.

Other students drew broader conclusions about the country based on their safety observations. For example, a student states:

> While walking through the factory we noticed a man welding with no mask. The small experience went to show something about Chinese culture; the speedy growth that the Chinese economy has had, and the regulations, and all sorts of things that we have in America, have not had time to take a real foothold like it has in many other world superpowers. [China 28] [Codes: Activities/Processes + Economic, Political].

These students suggest safety standards and regulations as solutions for issues around safety. These solutions are largely drawn through a comparison to what they think the US has in place regarding safety. While the students interpret this safety culture as lacking standards or practices, they do not demonstrate an awareness of US manufacturing practices that prioritise low labour costs in a global political economy (Levenstein and Rosenberg 2012).

Gender in engineering

In addition to safety practices, students on the China track also reflected on gender in engineering. One student described an incident where the representation of women in engineering was discussed:

> The visit to Pansoft Data Solutions also showcases how pervasive it is to put females in the backseat in many circumstances. During the meeting with the Pansoft's executives, they asked a question about females in STEM in the US and a male student went to answer the question, but [our track leader, who is a woman] stopped him and told him to allow a female student to answer that question as they would know the most about females in STEM as they are females. This incident shows that even though US is a more liberal country than China, US still has places to improve in allowing women to speak for themselves rather than being spoken for. There were 3 executives (two males, one female), one translator, and one intern from Pansoft talking to us, but throughout all of that, only the two male executives were talking, and the female executive never spoke. It is not known why the female executive did not say anything, but China is not a great country in terms of gender equality especially in certain fields of STEM. [China 33] [Codes: Activities/Processes + Social, Cultural].

This student took their experience with this incident and drew a macro-level conclusion about gender equality in China. Another student noticed the theme of gender recurring throughout several visits:

> I noticed a reoccurring theme throughout our trip. [Woman Track leader] asked many of the companies we visited about women in engineering in China, and this sparked my interest. When [Woman Track Leader] asked our presenter and 'engineer' from earlier about women in engineering in China, she answered by saying how she wasn't actually an engineer, and how she was more of a teacher within the company. She said there were practically no women engineers in the company, partly because of gender norms and partly because women weren't as adept to lifting the heavy equipment in the steel factory. This theme repeated throughout different visits, as many companies stated how there are almost no women in engineering in their company. This opened my eyes to how different countries and their societal norms have effects on gender gaps, and how engineering is viewed/interpreted in different parts of the world. Although it would seem that the US is ahead of countries like China when it comes to gender equality in employment, there are many other factors that are important in China's case. It seems that many women don't actually want to be engineers. They also seem to not be getting the same opportunities as men because of this lack of desire, and just because of how their long lasting and proud culture still prevails in the twenty-first century. This helped to reinforce the idea I had that it seems that China is not concerned with the rest of the world in a sense, as they practice the same culture as they have for so many centuries. They seem very reserved in just keeping to their business, on the national and personal level. [China 25] [Codes: Physical Objects/Artifacts, Activities/Processes + Social, Cultural].

This student interpreted the gender gap in China through the lens of national competition: they saw the US and China in competition with each other. This student also interpreted the gender gap through the lens of national culture: they saw US culture as more supportive of women in engineering than Chinese culture.

Automation

Automation came up on both tracks but with different levels of interpretation. On the China track, students drew macro-level interpretations related to automation whereas UK/Ireland students drew more micro-level interpretations. As a macro-level interpretation, a student reflected:

> The visit to the Shanghai Baowu Steel Factory was very different from what I expected it to be. Before visiting, I was expecting to see a lot of workers in the factory attending to every part of the manufacturing process. However, when we toured the hot-rolled steel line, I saw, at most, five to ten workers total in a space that one would think would have a lot of workers, especially in China. When asked about this, our company guide explained that the number of workers was being reduced to cut costs and many were in the process of being replaced with automation. This shocked me to an extent because I have been taught that manufacturing jobs are moving to China because the labor is much cheaper there. However, this is simply no longer the case in many factories. We also saw a lot of automation in the SAIC General Motors factory where robots were used for stamping car panels, welding, and assembly of various parts of the cars. From this, it doesn't seem like manufacturing jobs in existing industries will ever come back to the US despite what politicians may promise. [China 34] [Codes: Knowledge/Information, Physical Objects/Artifacts, Activities/Processes + Economic].

This student had a belief about labour and manufacturing in the US and China going into the study abroad experience, and their experiences visiting companies abroad challenged their initial belief. When presented with new evidence, this student's beliefs shifted. Students on the UK/Ireland track also noticed automation in the companies they visited but did not draw the same macro-level conclusions based on the automation they observed.

The environment

On the UK/Ireland track, students' macro interpretations emphasised issues of climate change and green energy. One student noted that they 'saw a gigantic offshore wind farm' which led them to state that the 'difference between the US and the UK is their use of green energy / clean energy.' This student went on to state that 'The US's use of clean energy has focused on nuclear, whereas the UK's has a much larger variety of green energy tools in use, such as large solar arrays, wind farms, and increasing the number of nuclear power stations they have.' [UK/Ireland 5] [Codes: Knowledge, Activities/Processes + Economic].

A different student questioned the environmental focus they experienced in England against their experiences in the US:

> This company visit showed me a lot of things about engineering in England […]. I learned that England has a more environmental focus on their projects than we do in the United States. I wonder why that people in England are more concerned about climate change than we are in the United States. I would also like to know how they design their projects to be more environmentally friendly. [UK/Ireland 4] [Codes: Knowledge, Activities/Processes + Cultural].

Overall, there were fewer instances of students making macro-interpretations on the UK/Ireland trip. In one reflection, a student noted differences in US engineering and UK engineering, in which 'engineering in the UK is viewed more as public works and problem solvers, which is slightly different than in the US' [UK/Ireland 5]. While the student did not state how US engineering is viewed, they did go on to reflect that 'despite the different views of engineering, we work and learn in relatively the same way: as groups and teams who work together to solve a common problem or achieve a goal. Thus, engineering is engineering, at least when comparing the US and UK' [UK/Ireland 5] [Codes: Activities/Processes + Social, Cultural]. The cultural distance between the US and the two tracks may help explain why macro-level interpretations were more common amongst the China track students.

Micro-system interpretation (China 3%; UK/Ireland 22%)

By micro-system level interpretations, we refer to students' focusing on individual companies, business considerations, company stakeholders, design constraints. We saw more students on the UK/Ireland track make micro-system level interpretations than those on the China track. The themes in the micro-system interpretations consisted of automation, workplace dynamics, and teamwork. Automation came up in the macro-system interpretations as well. We differentiated this theme based on whether the student was talking about the topic at the level of a country or a company.

On the topic of automation, a student reflecting on a car manufacturing plant noted that they 'found it interesting that the majority of the plant was run by robots. I've heard in the news that jobs are being taken away from manufacturing, but the jobs are being given to robots.' The student reflected on these insights pertaining to different jobs, by stating that they 'learned that having an engineer design the Mini Cooper might be as important to one that designs the robots that actually build the Mini Cooper' [UK/Ireland 3] [Codes: Knowledge, Activities/Processes + Economic]. A different student also reflected on the role of engineers after visiting this site:

> The precision and elegance of these robots must have taken an insane amount of planning, with a very diverse design team. Software engineers need to make the robots know what to do in every unique scenario. Mechanical [engineering] makes them able to perform those functions. Systems engineers need to design a flawless and efficient way of passing parts through the production line without human assistance. [UK/Ireland 10] [Codes: Activities/Processes + Social].

In a different example, a student reflected on the global nature of an American-based company. They noted their surprise that 'a small town in Ireland would house the location of a large biomedical company from the United States, especially since it would be much further from locations in America.' This student emphasised the value of having people with different perspectives working together while drawing on prior experiences.

> When I have worked on group projects with people whose perspectives are different than my own, it can often lead to creating a better a solution since the solution can account for a wider variety of criteria. This also applies to biomedical engineering because culture can influence the overall design of a product and including people from different cultures on a design team can help to account for these differences to ensure that the product can be used by a wider variety of people. [UK/Ireland 23] [Codes: Physical Objects/Artifacts, Activities/Processes + Cultural].

On the China track, a student reflected on an uncomfortable experience at one Chinese company, and interpreted the experience as demonstrating the company's values rather than generalising to the national culture:

> A time that I felt a bit uncomfortable on the trip was during the visit to the Taiheng Mechanical-Electrical Parts Ltd company. During our time to ask questions, there came a point where there was a disagreement between our group and the company about the importance of design and the importance of customer service after selling a product. It was obvious that both sides thought they were right and that little ground was going to be given either way. The situation was resolved by moving on to a different topic, but I definitely learned a lot about that company's views on service for a product's lifetime after it's been sold. Because it was just one company, I am not going to generalize all of Chinese manufacturing as being opposed to customer service after the purchase, but it might be something to take into consideration if I ever have to find a manufacturer when I am in the industry. [China 36] [Codes: Activities/Processes + Cultural].

Students who integrated cultural and technical dimensions at a micro-systems level focused on connections related to individual companies, specific projects, or company stakeholders. These types of connections were often related to the themes of teamwork and workplace dynamics.

Personal and career interpretations: China 13%; UK/Ireland 22%

The third interpretation relates to students making personal and/or career connections in their reflections. This category overlaps somewhat with the micro-interpretation category. We differentiated based on which aspect (micro or career) students focused on more. Students reflected on their experiences by connecting their study abroad experiences to their lived experiences or their career aspirations.

Students on both tracks have reflected on automation to varying levels of interpretation. One student reflected on their experience growing up in the US Rust Belt to their experiences in an automated Chinese steel mill. They state,

> The mill was efficient and mostly automated: few workers were needed to operate the enormous machines. This was particularly of interest to me, a student from the Midwest/Rust Belt from Pittsburgh. I grew up in the shadows of closed down steel plants and poor communities that once relied on the steel jobs that had gone off to China. Now I was standing right here. Here were the jobs – but there weren't that many of them. In the area that I am from, ignoring some of his other ideas because they aren't entirely relevant here, Trump's isolationist trade ideas are almost unanimously popular. It was very interesting for me to come to China and see the steel industry here and observe the realities of what is happening: wherever the steel is produced in these modern times, it will never be factories full of thousands of workers like my community used to know. It will be many machines and a few dozen workers, wherever those few may be from. [China 45]. [Codes: Knowledge/Information, Activities/Processes + Economic, Political, Social].

This student draws from their personal experiences as they make sense of what they see in the automated steel plant. The student points out that contemporary political discourse in the United States may be unfounded as they look at the state of the workforce in a manufacturing plant.

On the side of career aspirations, a different student reflected on the experience of meeting a 'nontraditional' engineer nicknamed Dr. Bubbles. They state:

> During the visit, one of the engineers that talked to us focus on bubbles. He worked with the ability of bubbles to change sound frequencies and how bubbles could be used for cleaning. For that reason, someone on the trip with me called him Dr. Bubbles because he just submitted his dissertation. […] He was passionate about his work but also was able to articulate it in a calm and clear way. […] From that, I learned that a path in engineering does not have to be normal. There is no normal path in engineering. I can follow whatever path I want once I have my degree. I could work with food or with structure or with bubbles. As long as I follow my interests and apply the problem-solving skills to the situation, I can work anywhere with anything. Engineering is not a set field; it is a way of thinking and applying science and mathematics. [UK/Ireland 3] [Codes: Knowledge + Social].

Students who integrated cultural and technical dimensions at a personal or career-level focused on connections related to their lived experiences, personal interests, or career aspirations and trajectories. These types of connections related to students making sense of their lived experiences in the context of their study abroad experiential learning as well as, learning about different applications and types of engineering practice.

Discussion and implications

We discuss two takeaways from this study and their relevant implications. First, we discuss how cultural distance and authentic peripheral participation influence students' systems thinking on different engineering study abroad experiences. Based on the findings, travel destination appears to affect the kinds of contextual elements that students draw out, so students may need different support in developing systems thinking depending on cultural context. Second, we discuss some limitations of using a framework that demarcates the contextual and technical dimensions of engineering. Lastly, we address some challenges with over-generalizations made by some participants about the cultural contexts they experienced and offer frameworks to address this tendency in future work.

Systems thinking and engineering study abroad experiences

Our work answers the calls to explore a wider range of assessment approaches and learning outcomes in international education (Davis and Knight 2023; Deardorff 2015; Salisbury 2015; Wong 2015). While much of the prior research of study abroad has focused on intercultural competence and related learning outcomes, including our prior research on the RSAP program (Davis and Knight 2018, 2021), these findings demonstrate the potential for students to explore systems thinking topics within an engineering study abroad experience. The students in our study considered systems thinking through a range of different technical and contextual elements, which they integrated in different ways without prompting – not from their instructors, nor the study abroad design, nor the reflection prompts (Appendix 1). This finding is a promising step towards addressing the concern that engineering students struggle to connect intercultural competence to their technical discipline (Davis 2020; Davis and Knight 2021). Although students made some connections without intervention, systems thinking provides a framework for helping students make more and richer connections between technical and contextual elements of engineering. Future programs could intentionally design systems thinking in engineering study abroad programs using this framework. These intentionally designed systems thinking frameworks could also be used in other situated learning environments like industry internships, design experiences, and community service.

Through a framework focused on contextual and technical dimensions in engineering, we observed differences between the two tracks that we studied, which suggests that future programs interested in supporting students' systems thinking development may want to support their learning differently based on national or cultural context. This finding aligns with our earlier research on intercultural competence development in both RSAP and research abroad programs (Davis and Knight 2018). This result also provides insights into the types of experiences that may support the development of systems thinking.

Students travelling in a location with more clearly observable contextual variables were more likely to more naturally reflect on those variables' impact on engineering work. Engineering educators could explore other ways of embedding students into authentic complex systems and asking them to reflect. Could this type of experience be mimicked in a classroom or on-campus setting? Based on this research, in which students reflected on more contextual dimensions in settings of higher cultural distance, students may benefit from being deliberately guided to reflect on contextual dimensions when participating in places that are similar in culture. For example, students conducting senior design projects, completing internships, or visiting companies near their own regions may need more prompting to see and value the contextual elements as part of their experience. But even individual countries do not have monolithic cultures, and there is opportunity to engage students in authentic experiences with high cultural distance at the local level as well (e.g. rural/urban divides in the US). Without this scaffolding for contextual dimensions, we would expect these results to be similar to students on the UK/Ireland track than those on the China track. Based on these findings, we recommend further study on the general effect of study abroad on systems thinking and the specific effect of the study abroad destination.

We interpret these findings through the lens of situated learning theory, which suggests that engaging with a community of practice through legitimate peripheral participation is a central part of learning (Lave and Wenger 1991). For systems thinking skills, it seems that a more complex community of practice (i.e. more visible/accessible contextual variables) may support greater learning. Overall, our findings support systems thinking as a framework that can inform the design and assessment of engineering global learning experiences.

Systems thinking as contextual and technical dimensions

In this study, we used a systems thinking framework to study how students reflected on and drew connections between different contextual and technical dimensions (Grohs et al. 2018). Importantly, there were several instances in the reflections where students' reflections depicted the contextual and technical elements as inextricably bound, where demarcation proved extremely difficult. In this sense, students were depicting engineering as a sociotechnical system, in which there was no artificial boundary between the contextual and technical elements of engineering practice (Cech 2014; Faulkner 2000; Leydens and Lucena 2018; Smith et al. 2021).

The categorizations from the theoretical framework that we use to examine students' reflections as contextual and technical perpetuate a divide between these two interdependent and interrelated concepts (Jesiek et al. 2020; Smith et al. 2021). While this demarcation is useful as it situates our study within the engineering education scholarship on systems thinking and contextual learning in engineering, we contend that this framework's dualism is limited in its examination of interrelation. Our study's examination of integration between dimensions helped address some of these limitations but still constructs a limited classification of what counts as integration and what does not (Kleine, Zacharias, and Ozkan 2023). A future approach could be to examine students' understanding of sociotechnical systems in connection to their worldviews to bring attention to the ways students see the world, which influences how they see engineering systems.

Challenges and opportunities with contextual and technical integration

As part of our second research question, we found that students on the China track made more macro-interpretations that generalised about all of Chinese culture or its values, while students on the UK/Ireland track made more micro-interpretations that considered their observations as just a local practice and not representative of an entire nation. Generalising from a learning experience is not inherently bad, as it is a way people make sense of their surroundings (*e.g.* mental models; Kania, Kramer, and Senge 2018; Seel 2006). However, we believe the correlation of students' level of generalisation with their track's cultural distance – *i.e.* that the greater the cultural distance

(China), the greater the tendency to generalise from anecdotes to an entire culture – is problematic and suggests an opportunity for educational improvement.

These concerns are not isolated to study abroad experiences. Scholars of culturally relevant pedagogy (Berryman et al. 2013; Castagno and Brayboy 2008; Ladson-Billings 1995) and border-crossing (Clark, Dodd, and Cole 2008; Grimberg and Gummer 2013) have discussed the harms of deficit-based thinking about different cultural backgrounds. With deficit-based thinking, there is an assumption that cultures that do not meet the narrow standard of success or progress are less progressive. Instead of deficit thinking, scholars contend that asset-based lenses are necessary for people from different cultures and backgrounds to form mutually meaningful relationships. In the context of engineering study abroad and systems thinking, we suggest an integration of asset-based reflection prompts to help students contend with different knowledges, ideas, and tensions instead of defaulting to a comparison to their home country – in our case, the United States.

Conclusions

In this study, we examined how students in an engineering study abroad program reflected on their impressions of situated engineering practices as the connections they drew between various contextual and technical dimensions. We evaluated 47 engineering students' reflections across two tracks abroad – China and UK/Ireland. Through a framework adapted from Grohs et al. (2018), we were able to assess students' systems thinking on an engineering-focused study abroad experience – a setting that challenges students to make sense of real-world, situated complexities.

We compared the reflections in student journals collected from two study abroad tracks, China and UK/Ireland and found that students on each track made comparable technical observations. However, the students on the China track made more contextual observations, and more frequently integrated the technical and contextual factors of their observations. We analyzed the extent of integration between the dimensions along a spectrum of micro, macro, and personal/career connections. The integrations made by students on each track also differed: students on the China track more frequently drew interpretations at the macrosystems level of a country or culture, while students on the UK/Ireland track tended to focus on the microsystem of a company or individual they observed. Overall, the student reflections from the China track drew more connections between technical and contextual aspects than the students from the UK/Ireland track. The cultural distance between these two track destinations is important to attend to as we interpret the ways students combined and integrated contextual and technical aspects of engineering in their reflections.

Engineering educators have long emphasised the importance of training engineering students in systems thinking, so that engineers consider both technical and contextual factors in their work. While prior scholarship has worked to develop and evaluate students' systems thinking in formal settings, e.g. via in-classroom case studies, we contribute new insights about how engineering students can develop their systems thinking in situated study abroad experiences and use these insights to reconsider how systems thinking can be developed in more accessible experiences closer to home. These insights are relevant for industry professionals or other experts who are interested in designing student learning opportunities and workforce through situated learning pathways like internships.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendices

Appendix 1

[Program Name] Journal Prompt 2019

The four journal entries will be divided evenly over the course of your trip, so each entry should reflect on 3–4 days of the trip. You are encouraged to make a few bullet point notes each day about your thoughts so that when you sit down to write an entry, you have something to go on. It can also be helpful to look over pictures from each day to remind you of key events and activities.

For each entry, identify 2–3 important experiences or ideas that you have been thinking about or were meaningful to you based on the events of the past few days. For each experience or idea, write 1–2 paragraphs where you explore the topic in more detail by asking yourself questions (from the template, or your own) and writing your answers. This reflection process should focus on making connections, exploring ideas, challenging your beliefs, recognising patterns, or identifying applications of things you have learned. You can write about what happened and what you did if you would like (some students find it helpful to remember the trip this way), but 1–2 paragraphs should focus on reflective topics specifically.

[Program Name] Reflection Template

Reflection Activities:

- Ask yourself questions
- Talk about your answers with other people
- Think about how you can apply what you learn

If you learned new information, you could ask yourself:

– How is this different from how things are at home or in other countries?
– Why do I think this is the case? Are there cultural influences I should take into account?
– What else am I interested in learning related to this topic?

If you had an interesting/exciting experience, you could ask:

– What was interesting to me about this experience?
– How can I relate this experience to what we learned in [Program Name] class, [First Year Engineering Course Sequence], or other experiences I have had?
– How might this experience influence me in the future?

If you had an uncomfortable experience, you could ask:

– What about this experience made me uncomfortable?
– What is something I might not have understood about the situation?
– How can I try to learn from this experience?

If you were surprised or confused by something, you could ask:

– Why was I surprised/confused? What was I expecting that did/did not happen?
– What can I learn about the local culture through this experience? Is there more information I can gather to understand the situation better?
– How can I connect this experience to my own life?

Other general questions:

– What are key cultural differences that I have noticed?
– How is my perspective changing on: engineering, the world, my own culture, my career goals, or anything else?

Appendix 2. Frequencies and percentages of technical and contextual codes used to create Figure 2

In our analysis, we first identified the reflection excerpts that demonstrated technical thinking. We coded these technical excerpts for the different technical and contextual thinking types described by our theoretical model, the Grohs et al. (2018) systems thinking framework. Table 5 summarises the results of this analysis.

Table A1. Technical and Contextual Code Frequencies

	China # Excerpts	China % of Excerpts	UK/Ireland # Excerpts	UK/Ireland % Excerpts
Technical Aspects of Engineering Work in Reflective Journals				
Any Technical Aspect	64	100%	55	100%
Knowledge & Information	19	30%	16	29%
Physical Objects or Artifacts	30	47%	27	49%
Activities or Processes	46	72%	42	76%
Contextual Aspects of Engineering Work found in Technical Reflection Excerpts				
Any Contextual Aspect	52	81%	27	49%
Economic	22	34%	9	16%
Political	29	45%	1	2%
Social	14	22%	8	15%
Cultural	20	31%	16	29%

The next step in our analysis was to understand how often participants reflected on both the technical and contextual dimensions of engineering in a single excerpt. Table A2 summarises our results across both destinations, showing the technical dimensions in the left column and the contextual dimensions across the top. Table A3 and A4 show dimension breakdown for each track. These are the tables used to create the Sankey diagram in Figure 2.

Table A2. Percentage of journal excerpts where students integrated social and technical dimensions (both destinations, *N* = 47 journals). Darker colour indicates higher percentage.

Total	Economic	Political	Social	Cultural
Knowledge & Information + Context	7%	5%	4%	10%
Physical Object/Artifacts + Context	11%	8%	8%	17%
Activities/Processes + Context	20%	20%	14%	20%

Table A3. Percentage of journal excerpts where students integrated social and technical dimensions (China track, *N* = 23 journals). Darker colour indicates higher percentage.

China	Economic	Political	Social	Cultural
Knowledge & Information + Context	5%	5%	3%	6%
Physical Object/Artifacts + Context	5%	8%	5%	8%
Activities/Processes + Context	16%	19%	8%	12%

Table A4. Percentage of journal excerpts where students integrated contextual and technical dimensions (UK/Ireland track, *N* = 24 journals). Darker colour indicates higher percentage.

UK and Ireland	Economic	Political	Social	Cultural
Knowledge & Information + Context	2%	0%	1%	4%
Physical Object/Artifacts + Context	6%	0%	3%	8%
Activities/Processes + Context	4%	1%	6%	8%