

Enhancing Student Learning in Innovation Competitions and Programs

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Abstract

Universities have developed various informal learning experiences, such as design challenges, hackathons, startup incubator competitions, and accelerator programs that engage students in real-world challenges and enable environments for creative problem-solving. However, limited studies explain the extent and nature of the impact of student innovation competitions and programs (ICPs) on participating students' innovation mindset. Current literature was analyzed using network analytics techniques to discover relations among ICPs and innovation skills. Using an online instrument, 194 students from two universities categorized and ranked skills/abilities they gained as the most or least improved due to participating in ICPs and their challenges during ICPs. The collected data was analyzed to gain insight into the student's experiences and perceptions. The findings of this study showed that overall, students rated technical and problem-solving skills higher than some innovation mindset skills. However, the findings also suggested that incorporating more entrepreneurial elements in ICPs may improve the innovation mindset learning outcomes of ICPs. The findings contribute to how ICPs can be better designed to foster an innovation mindset, mitigate challenges that students come across, and increase the participation of all students.

Keywords: STEM, engineering competitions, entrepreneurship, innovation, skills, mindset

1 Introduction

Student competitions have long been essential to STEM education (Riley & Karnes, 2005). Over the past decade, Innovation Competitions and Programs (ICPs) have surged in popularity within engineering and STEM disciplines, driven by a growing emphasis on entrepreneurship and innovation. ICPs, which encompass start-up incubator competitions, design challenges, hackathons, accelerator programs, and innovation boot camps, among others, serve as non-credit learning experiences that enhance the formal education of STEM students. These experiences are increasingly critical for achieving broader objectives in STEM education, acting as gateways to innovation and entrepreneurial ecosystems in many colleges.

ICPs are organized by a diverse array of entities, including colleges, public and private foundations, government units, and corporations. STEM students are strongly encouraged and sometimes incentivized to participate in these co-curricular activities to improve their technical and professional skills. Additionally, ICPs present students with complex, real-world problems inspired by Grand Challenges such as climate change, sustainability, health, cybersecurity, poverty, and social justice. Addressing these multifaceted issues requires a multidisciplinary approach, and ICPs, often open to students from all majors, provide rare opportunities for interdisciplinary collaboration.

Therefore, ICPs are essential in forming innovative engineers through design activities beyond the formal curriculum (Mikesell, Sawyers, & Marquart, 2012; Schuster, Davol, & Mello, 2006). Given the increased emphasis on innovation and entrepreneurship within ICPs, an important question arises: to what extent do ICPs cultivate entrepreneurial and innovative skills among students, and what factors influence their effectiveness? Despite the significance of this question, empirical research from the student perspective remains limited. To fill this gap, this paper investigates ICPs from students' viewpoints in two key dimensions: (i) the role of ICPs in developing students' innovation-related skills and abilities, and (ii) the challenges students encounter during ICPs. Specifically, we aim to answer the following research questions: (R1) What skills/abilities do students perceive as most improved after participating in ICPs? (R2) Which types of ICPs are more effective in enhancing skills/abilities related to innovation? (R3) What factors influence the student outcomes and experiences related to innovation in ICPs? (R4) What are the challenges that students experience during ICPs?

Answering research questions R1 to R3 can help program organizers identify strategies to enhance the effectiveness of ICPs in developing innovation skills and abilities. Insights from R4 can lead to practical interventions to improve student access and incentivize participation in ICPs. To address our research questions, we conducted an empirical study on the learning outcomes and challenges of ICPs at two universities. Additionally, we comprehensively analyzed publications on ICPs to understand their impact on shaping engineers as innovators. Our findings contribute valuable knowledge for designing more effective ICPs that foster an innovation mindset and address the challenges faced by students during ICPs. Section 2 reviews the concept of an innovation mindset, the role of ICPs in fostering this mindset among students using a topical analysis, and the associated challenges with ICPs. Section 3 presents the

research methodology and statistical analyses of the collected data. Section 4 provides interpretations and implications of the findings, and Section 5 discusses limitations of the research and collected data.

2 Literature Review and Background

In this section, we review the characteristics of an innovation mindset, the role of ICPs in fostering this mindset and skills, and the challenges students encounter in these programs. To gain a comprehensive understanding of the relationship between innovation skills and ICPs, we conducted a topical analysis of publications related to ICPs and used a network analytics approach to examine the emerging topics in the existing literature. This network analytics approach offers a holistic view of the literature and presents current trends in ICPs.

2.1 Innovation Mindset

An essential objective of student competitions is to foster an entrepreneurial and innovative mindset among engineering students (Konak, Kulturel-Konak, Schneider, & Mehta, 2023). According to Dweck (2008), a mindset is a combination of attitudes, behaviors, and beliefs that shape how individuals establish and pursue goals, respond to challenges, and determine their likelihood of success. An entrepreneurial mindset, on the other hand, is characterized by the ability to act quickly and mobilize resources, especially in unpredictable situations (Ireland, Hitt, & Sirmon, 2003). Traits such as opportunity-seeking, adaptability, risk-taking, creativity, perseverance, empathy, and lifelong learning are commonly associated with successful entrepreneurs (see (Naumann, 2017) for a review). Based on these definitions, an innovation mindset can be defined as a set of beliefs and attitudes that lead to developing the capacity to produce valuable novelty. There is also a distinction between individual innovativeness and the innovation mindset. For example, Hunter, Cushenbery, and Friedrich (2012)'s conceptual model of innovativeness includes constructs, such as knowledge, skills, and abilities, while the innovation mindset emphasizes dispositions, attitudes, and propensities (Fitri & Pertiwi, 2019). Couros (2016) describes eight characteristics of an innovator's mindset: empathetic, problem finders/solvers, risk takers, networked, observant, creator, resilient, and reflective. Konak, Kulturel-Konak, and Liu (2023) define a comprehensive instrument to assess entrepreneurial mindset and innovative thinking skills in multiple dimensions, including tolerance in task ambiguity, risk acceptance, opportunity seeking, action orientation, passion for business, resourcefulness, need for achievement, personal growth, creativity, opportunity alertness and awareness, teamwork, networking, and financial literacy. The Kern Entrepreneurial Engineering Network (KEEN)'s Entrepreneurially Minded Learning (EML) Framework (Wheadon & Duval-Couetil, 2016) categorizes engineering skill sets into three areas: opportunity, design, and impact. Opportunity-related skills involve identifying and assessing the potential of new ideas and technologies. Design skills refer to the ability to identify technical requirements, create prototypes, and continuously refine designs based on testing. Impact skills are about understanding the societal implications of engineering solutions, developing partnerships and relationships, and being

able to communicate the value of those solutions in economic terms. KEEN’s EML framework advocates that engineering students can better address complex problems by mastering opportunity and impact skills in addition to design skills. Combining engineering skills with curiosity, connections, and creating value (the three elements of an entrepreneurial mindset), students can make innovative solutions that address real-world problems and drive positive change in society, business, and technology.

2.2 ICPs, Benefits, and Innovation Mindset: A Network Analytics Approach

In the literature, publications focusing on ICPs introduce mainly the design of programs or student projects (e.g., (Fulton, Schweitzer, & Dressler, 2012; Laud, Betts, & Basu, 2015; McGowan & Cooper, 2008; Mui Yu, 2013; Straub, 2020; Taylor & Clarke, 2018; Zimmerman, 2012)). These studies usually concluded that student competitions positively affect participants, as summarized in a review paper (Kulturel-Konak, 2021). ICPs offer many benefits and experiences for students, such as teamwork (Habash, Suurtamm, & Necsulescu, 2011), peer interactions and leadership, promoting creativity (Hassan et al., 2014), gaining self-efficacy and enthusiasm, building a growth mindset, working on real-world applications, accessing informal mentorship (A.J. Prince, Kulturel-Konak, Konak, Schneider, & Mehta, 2022), and connecting with employers (Adorjan & Maturro, 2017; Buchal, 2004; Schuster et al., 2006). Moreover, participating in an engineering competition team provides practicing leadership skills within a technical domain (Wolfinbarger, Shehab, Trytten, & Walden, 2021). Student competitions also go beyond teaching technical and discipline-specific skills and may offer students soft skills (Gadola & Chindamo, 2019). In engineering education, senior capstone projects have become typical venues for teaching soft skills; however, these are often limited by class time and curriculum expectations (Mikesell et al., 2012). Capstone projects, by nature, are towards the end of students’ educational careers, and therefore, students may not have time to practice their newly developed soft skills. Previous research has indicated that students tend to develop their understanding of ethical dilemmas (Esparragoza, Konak, Kulturel-Konak, Kremer, & Lee, 2019), global issues (Kulturel-Konak, 2020; Kulturel-Konak, Konak, Kremer, & Esparragoza, 2019), and teamwork skills (Konak, Kulturel-Konak, & Cheung Gordon, 2019) at a slow pace during their education. However, students who engage in experiential learning activities tend to demonstrate more significant progress in these soft-skill areas. Therefore, ICPs are essential in forming innovative engineers through design activities beyond the formal curriculum (Mikesell et al., 2012; Schuster et al., 2006).

To better understand the benefits of ICPs and their relation to the innovation mindset, we performed a holistic review of the previous publications using a network analytics approach. We performed a topical analysis of publications related to ICPs to investigate their learning outcomes related to entrepreneurship, innovation, and innovation mindset. The dataset for the topical analysis was obtained from the Web of Science by performing a topic search using the search terms *hackathon*, *student competition*, *student contest*, or *pitch competition* or its derivatives considering only STEM fields since 2001. We did not include search terms associated with innovation or entrepreneurship because our objective was to investigate to what degree the

ICP-related publications have referred to innovation-related outcomes and skills. Preliminary data cleaning involved deleting duplicate publication records, publications without keywords, opinion pieces, and news articles. The final data set included only journal articles and conference proceedings. Initially, we extracted 1,139 keywords from 501 publications. We post-processed the keywords by replacing similar words with the same meaning (e.g., mapping keywords *contest*, *contests*, *international student competition*, and *competitions* to the keyword *competition*) or merging keywords into broader concepts (e.g., merging *machine learning* and *deep learning* into *artificial intelligence*).

We used VOSViewer (Van Eck & Waltman, 2010) to identify the keywords that occurred more than four times and how frequently they co-occurred in the publications. We obtained a keyword network of 59 nodes (keywords) and 457 links whose weights represented how often keywords appeared together in the publications. This network was analyzed using the graph visualization and exploration software Gephi. We used the fast community detection algorithm (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008) to identify densely connected keyword clusters. Figure 1 illustrates the clustering of the 59 final keywords into six distinct groups, with the thickness of the links representing the strength of the relationships among them. Arbitrary colors are used to show the clusters that have formed. In addition, only the links with high strengths are included in the network plot to better present critical relationships among the keywords.

As seen in Figure 1, the keywords *hackathon*, *competition*, *education*, *innovation*, and *teamwork* had the highest frequency of occurrence. The cluster analysis identified two large clusters formed around the two most frequent keywords, *hackathon* and *competition*, as indicated by the purple and light blue clusters in the figure—these two keywords group together with different types of ICP topics. The keyword *hackathon* was associated with the keywords, such as *app development*, *software*, *participatory design*, *smart city*, *healthcare*, *public engagement*, and *community* in the purple cluster, *artificial intelligence* and *cybersecurity* in the green cluster, and the keyword *competition* was more frequently associated with the terms: *vehicle*, *autonomous systems*, and *robotics* in the red cluster. The term *competition* was more frequently associated with traditional student engineering contests that involve project-based, long-term engagements, such as Formula SAE, Mini Baja, Robotics, and other vehicle design competitions. Interestingly, the keywords related to pedagogical strategies, such as *project-based learning*, *active learning*, and *experiential learning*, were more frequently associated with the term *competition*. In contrast, the keywords *informal learning* and *collaborative learning* were more strongly linked to the keyword *hackathon*. These observations suggest that ICPs support student learning by providing experiential learning opportunities outside the traditional classroom setting.

Another emerging keyword group was related to *diversity*, *equity*, and *inclusion* (DEI) and the underrepresentation of females (*gender*) in STEM fields (*stem*), as shown in the brown cluster in Figure 1. Particularly, the keywords *DEI* and *gender* were strongly connected to the keyword *hackathon*. Two contradictory phenomena could explain this strong relationship. Firstly, some hackathons specifically aimed to recruit females and other underrepresented students into STEM programs (Byrne,

entrepreneurship and help them build entrepreneurial mindsets (Bodolica & Spraggon, 2021). In our analysis, the keywords *design thinking*, *prototyping*, *teamwork*, *creativity*, and *problem-solving* were clustered together (the green cluster), and they were strongly connected to *hackathon* and *innovation* keywords. Similarly, the keywords *innovation*, *entrepreneurship*, *idea generation*, and *participatory design* were clustered together with the keyword *hackathon*. The strong connection observed between the keywords *hackathon* and *innovation* is noteworthy. Student ICPs provide an environment in which students are exposed to critical thinking, problem-solving, and project management skills in a risk-free environment (Bridgestock, 2021). In addition, ICPs offer students an opportunity to showcase their skills in various areas without being criticized. For example, ICPs overall, especially hackathons, promote the notion that all ideas are good and encourage students to explore high-risk ideas, fostering innovation and creativity through supportive communities that allow outside-the-box solutions (Kayastha, 2017). Research suggests that students are more likely to engage their curiosity and imagination when they feel socially supported within the learning environment (James & Brookfield, 2014) and the cost of failure is low. The learning opportunities in ICPs are unique because these programs enable students to work on their innovations through the whole process, from ideation and prototyping to the presentation (Samson, 2010). Furthermore, ICPs encourage students to adopt innovative techniques and develop their ideas and skills throughout the process. Students can leverage ICPs to raise startup seed capital and tap into funding networks (Bridgestock, 2021). Thereby, ICPs can play an important role as facilitators of startups in economically distressed regions (Caiazza, Richardson, & Audretsch, 2015) as well as innovation activity for a larger spectrum of the economy (Mueller, 2006; Owen-Smith & Powell, 2004). In this respect, ICPs can serve as a recruitment ground for innovation and entrepreneurial ecosystems. Another way ICPs promote innovation is by introducing students to processes or toolboxes of innovation and providing practices for critical thinking skills (James & Brookfield, 2014; Samson, 2010). ICPs engage students in further design activities and enable them to apply their classroom learning (Mikesell et al., 2012; Schuster et al., 2006). Learning the innovation process can help students build innovative/growth mindsets (Bodolica & Spraggon, 2021).

Practicing teamwork and collaboration is a key learning outcome of ICPs (Adorjan & Matturro, 2017; Buchal, 2004; Schuster et al., 2006; Wolfenbarger et al., 2021). Our analysis showed that keywords like *teamwork*, *collaboration*, and *multidisciplinary* are closely linked to *hackathon*. We also observed a trend of *outside collaboration*, which includes terms like *community engagement*, *industry collaboration*, and *public collaboration*. These trends highlight ICPs' growing role in connecting students with their local communities and industry projects. Top employers, especially in IT fields (Bridgestock, 2021), support ICPs to identify and recruit talent, providing networking opportunities for students (Adorjan & Matturro, 2017; Bridgestock, 2021; Buchal, 2004; Schuster et al., 2006).

To analyze the trends in ICPs, we grouped the keywords into categories such as (i) topics (*robotics*, *vehicle*, *games*, *software*, etc.), (ii) pedagogical approaches (e.g., *project-based learning*, *experiential learning*, *informal learning*, etc.); (iii) innovation (*design thinking*, *participatory design*, *idea generation*, *prototyping*); (iv) collaboration

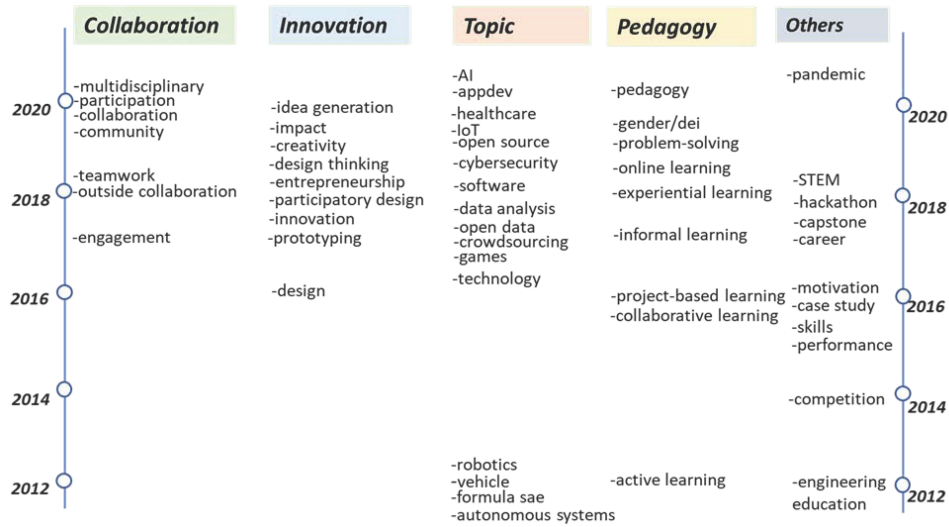


Fig. 2 The average citation age of keywords in different categories

(*teamwork, community, public engagement, outside collaboration, crowdsourcing*); (*v*) others. Figure 2 illustrates the keywords' average citation age along the *y*-axis for each group. This analysis showed that ICPs increasingly incorporate entrepreneurship concepts as keywords related to innovation and entrepreneurship, which have frequently appeared in recent years' citations. For example, the keywords *multidisciplinary, idea generation, impact, design thinking, entrepreneurship, and innovation* had an average citation age higher than 2018. The topics of recent publications focused on *artificial intelligence, app development, IoT, and healthcare*. Our holistic topical analysis of the relevant literature shows the growing relationship between ICPs and innovation and entrepreneurship-related learning outcomes.

2.3 Challenges and Problems Associated with ICPs

Several authors have highlighted potential negative effects of participating in competitions, such as frustration, anxiety (Cheng, Wu, Liao, & Chan, 2009; Gilbert, McEwan, Bellew, Mills, & Gale, 2009; Perez, Prince, Kulturel-Konak, & Konak, 2024; Reis, Dionne, & Trudel, 2015), and feelings of inferiority among low-performing students (Cheng et al., 2009). Other issues include a focus on winning over learning, social responsibility (Labossière & Bisby, 2009; Schuster et al., 2006), misplaced motivations, disappointments, and poor academic performance due to time management challenges (Schuster et al., 2006). Comparing and constraining ideas in a competitive setting may also hinder creativity (Hofstetter, Dahl, Aryobsei, & Herrmann, 2021). Some studies indicate that student competitions do not always result in learning critical professional skills (Brentnall, Rodríguez, & Culkin, 2018; Walden, Foor, Pan, Shehab, & Trytten, 2015). Time management is a common challenge, with heavy time demands causing stress and negatively impacting grades (Gadola & Chindamo, 2019; Kulturel-Konak, Konak, Webster, & Murphy, 2023; Pan, Shehab, Foor, Trytten, & Walden,

2015; A. Prince, Kulturel-Konak, & Konak, 2024; Schuster et al., 2006; Williams, Browne, & Carnegie, 2014). In a quantitative study, students mentioned that being introverted person prevented them from self-advocating for their ideas (Konak, 2025). Overall, these concerns are raised by studies done in different regions and countries.

Another issue is the gap between classroom skills and their application in competitions, leading to misconceptions about the engineering design process (Schuster et al., 2006). Team conflicts and difficulties in working with students from other disciplines are also common (Cheng et al., 2009; Kulturel-Konak, 2021; Kulturel-Konak et al., 2019). Additionally, diversity in ICPs remains a significant challenge. Hackathons often implicitly exclude women, contributing to gender disparities (Warner & Guo, 2017). Poorly designed hackathons may reinforce gender stereotypes and lead to feelings of exclusion among marginalized groups (Htun, 2019; Kos, 2019; A. Prince et al., 2024; Richard et al., 2015; Richterich, 2019; Taylor & Clarke, 2018; Walden et al., 2015). The lack of diverse social identity representations in marketing materials can also deter participation from diverse groups. (Murphy, Steele, & Gross, 2007).

3 Research Methodology

3.1 Procedures

A survey instrument was designed and sent to two university engineering students who participated in ICPs. The survey had three sections. The first group of questions asked students their motivations for participating in ICPs using value-cost-based questions given in (Kulturel-Konak, Konak, et al., 2023). In the second section, students were asked to select and rank three skills/abilities that they felt they had developed the most through their participation in ICPs among the skills/abilities given in Figure 4 and Table 3. This list of skills/abilities was compiled from interviews with 31 ICP organizers, specifically, from a thematic analysis of their responses to a question regarding their programs' learning objectives (Konak, Kulturel-Konak, Schneider, & Mehta, 2023) and KEEN's EML Framework (Wheadon & Duval-Couetil, 2016). These skills/abilities are categorized as design (D), opportunity (O), and impact (I), according to the components of the KEEN's EML Framework. Additionally, students were asked to choose up to three skills/abilities, without ranking, that they believed they had developed the least. The third section of the survey asked students to rank the three challenges they experienced the most during their ICPs. The list of challenges was based on previous research (Kulturel-Konak, Konak, et al., 2023; Kulturel-Konak, Leung, & Konak, 2023). Similarly, students were asked to choose up to three challenges they did not experience, without ranking them.

In the survey, we opted for ranking questions to understand how students prioritized their preferences and perceptions rather than just rating them equally, and their rankings provided more insight into what mattered most for students. In selecting the final lists of skills/abilities and challenges, a panel of students reviewed items for their face validity, which were revised accordingly. In addition, the number of items was attempted to be minimal to achieve a reasonable response rate but comprehensive enough to cover skills/abilities related to an innovation mindset.

Table 1 Survey Respondents’ Demographics

Variable	Level	University I		University II	
		Non-Eng. (n)	Eng. (n)	Non-Eng. (n)	Eng. (n)
Class Year	Lower	36	54	3	12
	Upper	26	28	12	23
Gender	Male	19	27	10	19
	Female	43	49	4	15
	Non-binary/third gender	0	3	1	0
	Prefer not to say	0	3	0	1
Ent. Family	No	35	66	10	26
	Yes	25	14	5	9
ICP Type	Tech Focus	1	27	6	14
	Solution Focus	61	55	9	21

3.2 Participants

Students were recruited to participate in the survey via emails or campus signage in the two universities in the Northeast USA. A total of 194 students completed all the select/rank questions relevant to the analysis. Table 1 presents the breakdown of the subgroup of participants. After reviewing the types of ICPs that students participated in, we categorized ICPs into two groups based on their primary focus: technical and solution. In technical-focused ICPs, students are expected to integrate different technologies to create systems with technical ingenuity (e.g., building a robot) or design and implement an innovative solution for a technical challenge (e.g., building a steel bridge). In solution-focused ICPs, students also design and implement solutions by considering the end-users’ needs (e.g., creating a sustainable engineering solution). It was observed that students from University I took part in fewer types of ICPs than those from University II. Moreover, the ICPs offered by the two universities differed in terms of the entrepreneurship level integrated into the programs. Some students in University II participated in programs that explicitly embedded entrepreneurship skills (e.g., ICPs based on the NSF I-Corps program that aimed to convert promising ideas into marketable products).

Although our primary target population was engineering students, ICPs were open to all students in both universities. As a result, about 43% and 30% of survey respondents were students from non-engineering majors in Universities I and II, respectively. We grouped respondents as engineering and non-engineering majors for a more detailed analysis. Figure 3 presents the distribution of participants by major at Universities I and II. As seen in Table 1, students in non-engineering majors mainly participated in solution-focused ICPs. In addition, we considered demographic variables such as gender, class year (lower level: first two years or upper level: other class years), and whether or not students had entrepreneurial family members.

3.3 Statistical Analyses of Student Rankings

This section presents the statistical analyses performed to address our research questions, along with justifications for the specific statistical methods utilized. The subsequent section discusses the outcomes and their implications. In this study, students were tasked with selecting and ranking a set of skills/abilities and challenges, which was different from rating multiple items that measured the same construct on a scale. For this reason, conventional reliability measures like Cronbach’s alpha could not be used to assess inter-rater reliability (IRR) and the scale’s consistency. Therefore, the analyses related to the reliability of responses focused on evaluating the

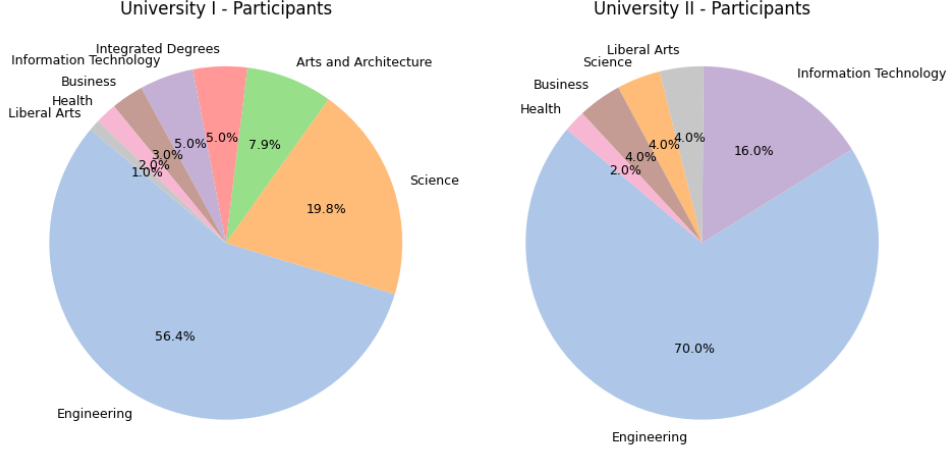


Fig. 3 Distribution of Participants by Major in Universities I and II ($n = 144$ for University I and $n = 50$ for University II)

extent of agreement in students' selections, specifically in terms of inter-rater agreement. We used the intra-class correlation (ICC) to demonstrate the level of agreement among participants with regard to their choices for the three most and least improved skills/abilities, as well as the three most-experienced and least-experienced challenges. ICC assesses the level of consistency or absolute agreement among the raters, and it is suitable when multiple randomly selected raters evaluate multiple subjects (Hallgren, 2012). We calculated the ICC values for the University and ICP type using R's ICC function with the parameters of the two-way mixed model, agreement type, and average unit. The ICC values were calculated for the most and least categories combined due to their interdependency (i.e., if an item was selected in the most category, it was not allowed to be in the least category). Table 2 summarizes the calculated ICC values, F -statistics, p values, number of raters, and number of subjects for each subgroup. The agreement among the raters is considered fair for ICC values between 0.40 and 0.59, good between 0.60 and 0.74, and excellent between 0.75 and 1.0 (Hallgren, 2012). Compared to these benchmarks, the calculated ICC values in Table 2 indicate strong agreement among the participants in each subgroup. The F -test assesses whether the observed ICC significantly differs from zero (i.e., there is no agreement). For all subgroups, the very small p values indicate statistically significant ICC values, rejecting the null hypothesis of no agreement.

Next, we calculated the ICC values to determine the level of agreement on the top three rankings of the most-improved skills/abilities and the most-experienced challenges. We could not perform the same analysis for the least-improved skills/abilities and least-experienced challenges because students selected these items without ranking them. Table 2 also lists the ICC values for the agreement on the top three rankings. The agreement on the rankings was strong, except for University II and technical-focused ICPs. Overall, students from both universities showed more agreement in ranking the challenges than in ranking the skills/abilities.

Table 2 Intra-class Correlation (ICC) for Student Agreement of the Skills/Abilities and Challenges

University	Type	ICC	<i>F</i> -statistic	<i>p</i>	ratars <i>n</i>	subjects <i>n</i>	
Skills/Abilities Selection	I	1	0.85	6.49	0.00	29	24
	I	2	0.85	6.49	0.00	115	24
	II	1	0.64	2.74	0.00	20	24
	II	2	0.46	1.82	0.01	30	24
Challenges Selection	I	1	0.90	9.62	0.00	29	20
	I	2	0.94	16.35	0.00	115	20
	II	1	0.69	3.14	0.00	20	20
	II	2	0.68	3.00	0.00	30	20
Skills/Abilities Ranking	I	1	0.80	4.71	0.00	29	12
	I	2	0.80	4.79	0.00	115	12
	II	1	0.36	1.52	0.13	20	12
	II	2	0.50	1.91	0.04	30	12
Challenges Ranking	I	1	0.85	6.18	0.00	29	10
	I	2	0.93	13.66	0.00	115	10
	II	1	0.54	2.05	0.04	20	10
	II	2	0.66	2.80	0.00	30	10

To answer research question R1, we tabulated the percentages of students who selected their top three most-improved skills/abilities and their three least-improved ones for both universities. Figure 4 illustrates the percentage (%) of students who ranked the skills/abilities among the most-improved or least-improved categories and their ranks (given in parenthesis) in each University. In the figure, the skills and abilities are sorted by their rank in the “University I Most Improved” category. Each skill/ability is marked with its respective EML category: D for Design, I for Impact, and O for Opportunity. The bars show the percentage of students who reported the most and least improvement in each skill/ability. The percentages and their corresponding ranks are displayed directly on the bars for easy reference. The most and least-improved percentages are stacked to demonstrate the consistency of the ratings for each skill/ability. To answer research question R4, we calculated similar statistics for the challenges faced by students. These results are summarized in Figure 5, sorted by the rank of the most-experienced challenges by University I.

To study research question R2, we created a new variable called rank score (RS) by coding and combining student selection and ranking of items in the most and least categories as follows:

$$rs_{jk} = 5 - r_{jk}^{most} - r_{jk}^{least}$$

where $r_{jk}^{most} = \{1, 2, 3, 4\}$ is the ranking of item k (skill/ability or challenge) by student j in the most category, with 1 representing the highest ranking and 4 representing “not selected”, and $r_{jk}^{least} = \{0, 1\}$ indicates whether item k is selected in the least category (1) or not (0). The resulting rs_{jk} ranges from 0 to 4, with 0 representing the least improved skills/abilities or least experienced challenges, and 4 representing the most improved skills/abilities or most experienced challenges. This RS variable allows for a more straightforward interpretation and statistical analysis of student perceptions. Figures 6 and 7 illustrate the mean RS of the skills/abilities and challenges, respectively, for University I and University II. In the figure, the bars represent the average scores, while the error bars indicate the variance of these scores. The skills/abilities and

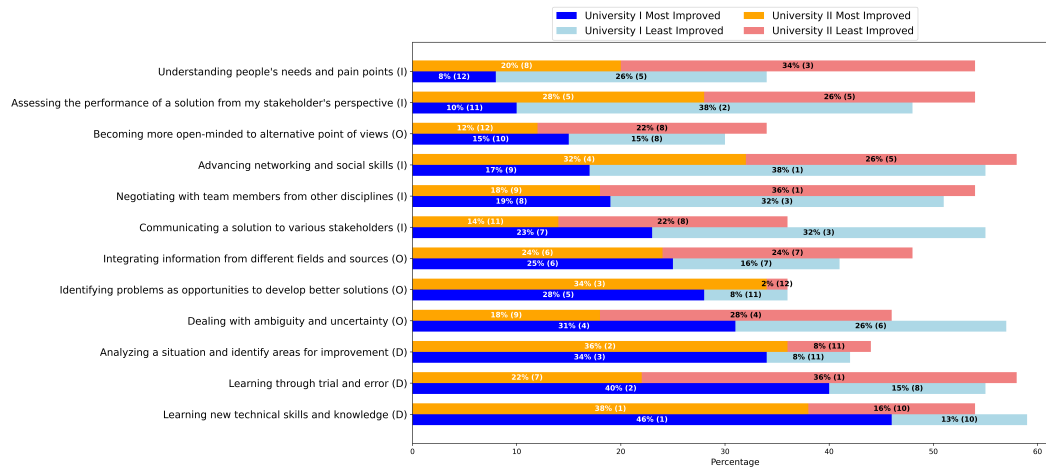


Fig. 4 The percentages of students who categorized skills/abilities as the three most-improved and three least-improved ($n = 144$ for University I and $n = 50$ for University II)

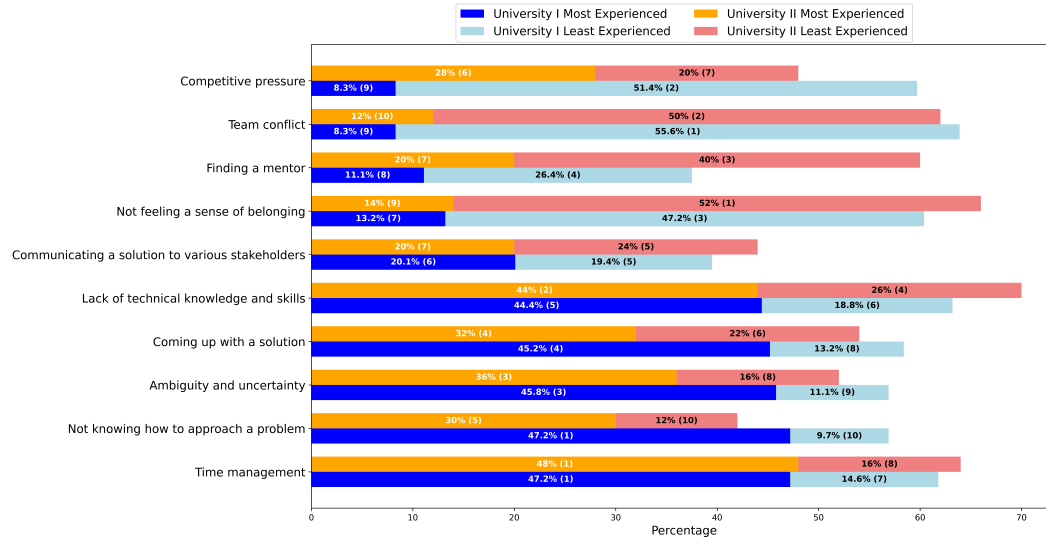


Fig. 5 The percentage of students who ranked the challenges as their three most-experienced and the three least-experienced ones ($n = 144$ for University I and $n = 50$ for University II)

challenges are arranged in descending order based on the mean scores from University I.

We performed Poisson regression analyses to examine how ICP Type (technical (0) or solution-based (1)), gender (male (0) or female (1)), family background (non-entrepreneurial (0) or entrepreneurial (1)), class year (CY) (first two years (0) or higher (1)), and major (other (0) or engineering (1)) influenced RS for each of the skills/abilities and challenges. Table presents only statistically significant Poisson

Table 3 Regression Coefficients of Poisson Regression Analyses

Skills/Abilities (EML Category) / Challenges	Regression Coefficients (β)				
	Uni.	Type	Gender	CY	Major
Learning new technical skills and knowledge (D)		-0.50			
Analyzing a situation and identify areas for improvement (D)					
Learning through trial and error (D)	-0.56	-0.40			
Advancing networking and social skills (I)	0.65		0.49		
Negotiating with team members from other disciplines (I)					
Assessing the performance of a solution from my stakeholder's perspective (I)	0.57	0.40			
Understanding people's needs and pain points (I)		0.51			
Communicating a solution to various stakeholders (I)		0.40		0.33	
Becoming more open-minded to alternative point of views (O)					
Dealing with ambiguity and uncertainty (O)					
Identifying problems as opportunities to develop better solutions (O)					
Integrating information from different fields and sources (O)					
Not knowing how to approach a problem					
Ambiguity and uncertainty					
Time management					
Coming up with a solution					
Lack of technical knowledge and skills					
Communicating a solution to various stakeholders		0.40			
Finding a mentor					-0.33
Not feeling a sense of belonging					
Competitive pressure	0.77	0.48			
Team conflict				0.48	

regression coefficients ($p < 0.05$) for table readability. The independent variable family background was insignificant in terms of all skills/abilities and challenges. Therefore, this independent variable is not included in the table. In addition to RS being a discrete variable, a Poisson regression was used because of two other reasons. First, the means and the standard deviations of RS are similar, as given in Figures 6 and 7. Second, the distribution of RS is asymmetrical (not following a Normal distribution). All independent variables were included in the models to account for confounding effects and interactions among the independent variables. We combined the two universities' data and used institutions (University I (0) and University II (1)) as a factor in the regression models to identify the common patterns. Table 3 displays only statistically significant Poisson regression coefficients ($p < 0.05$) for table readability.

Using correlation analyses, we also evaluated the extent to which the RS values in the two universities were parallel. The Pearson correlation coefficients between the two Universities' RS values were 0.548 ($p=0.055$) for the skills/abilities and 0.82 ($p=0.004$) for the challenges. These statistically significant correlations suggested that the ranking of students at the two universities, especially in terms of the challenges they experienced, were correlated, although they participated in different ICPs.

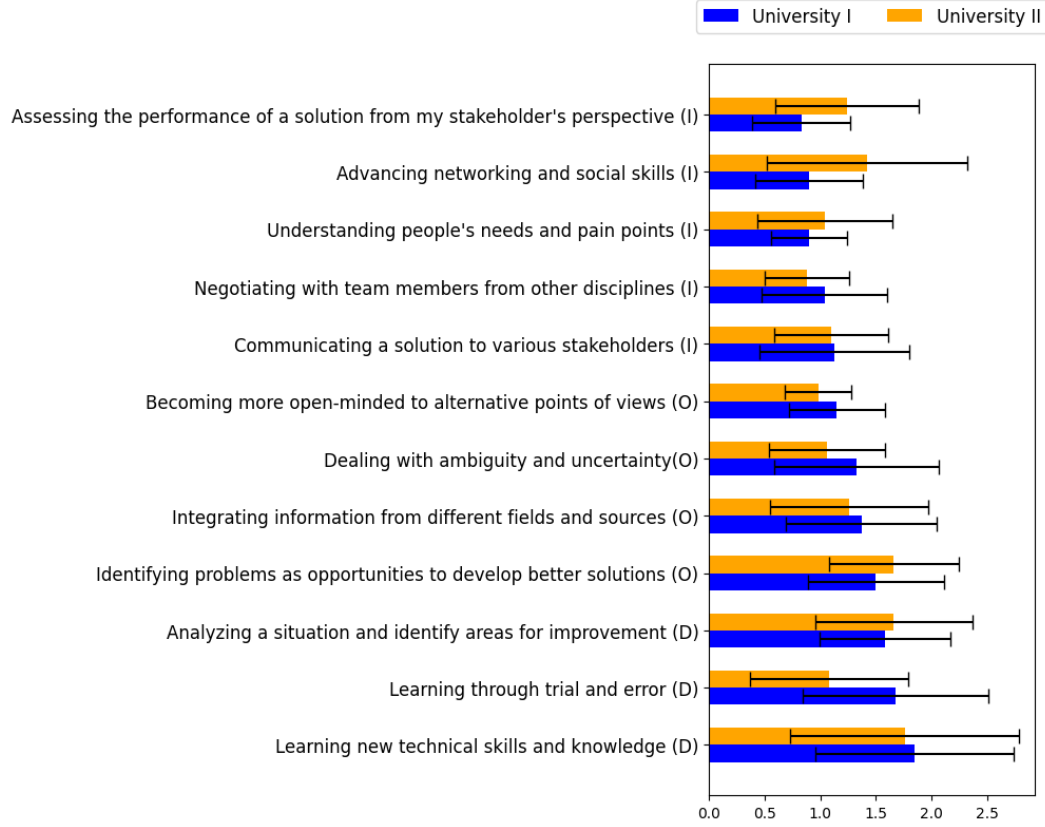


Fig. 6 The Descriptive Statistics of Rank Score (RS) for Skills/Abilities for University I and II (Bars: Mean, Error Barrs: Variance)

Next, we addressed research question R3, which examines the factors affecting student innovation mindset-related outcomes and experiences in ICPs by adopting a holistic approach. We categorized skills/abilities into three groups—design, impact, and opportunity—based on KEEN’s Entrepreneurially Minded Learning (EML) Framework (Wheadon & Duval-Couetil, 2016). Table 3 details the EML category for each skill or ability. To assess the importance that students assigned to the three components of KEEN’s EML Framework, we calculated an aggregate score for each component by summing the rank scores of the items within that category for every student. We then utilized the GLM package in R to fit Poisson regression models predicting the total rank score as a function of various independent variables. Our analyses revealed that ICP type was the only statistically significant factor, with $p < 0.05$. Table 4 presents the mean and variance values of the normalized rank scores for the EML Framework components and the obtained Poisson regression coefficients for the ICP type.

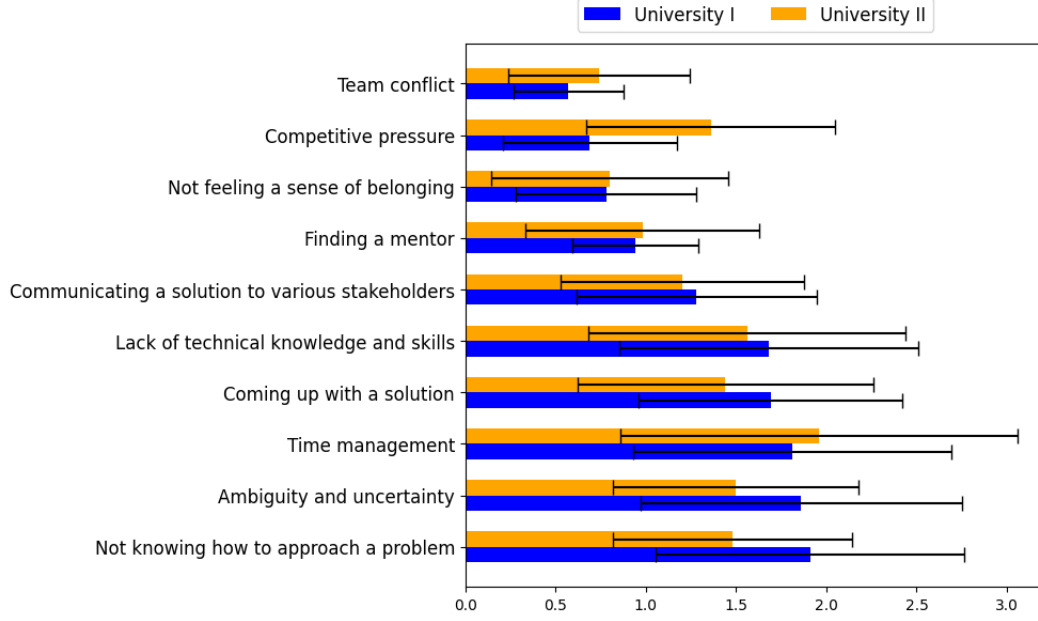


Fig. 7 The Descriptive Statistics of Challenges for University I and II (Bars: Mean, Error Barrs: Variance)

Table 4 The Means and Variances of the normalized rank scores of the EML framework components and the Poisson Regression Coefficients for ICP Type

	EML Component	Mean	Var	Type	p
University I	Design	1.704	1.222	-0.207	0.033
	Impact	1.632	0.777	0.218	0.049
	Opportunity	1.782	0.854	-0.044	0.669
University II	Design	1.500	1.568	-0.460	0.00
	Impact	1.920	0.788	0.237	0.063
	Opportunity	1.653	0.622	0.129	0.347

4 Discussions of the Results

In this section, we discuss the results presented in the previous section and their implications. Regarding research question R1, as shown in Figure 4, the students in both universities more frequently ranked “Learning new technical skills and knowledge,” and “Analyzing a situation and identifying areas for improvement” among their top three most improved skills/abilities compared to the other items. In University I, the top three skills/abilities were related to the design component of the EML Framework. On the other hand, impact-related skills/abilities such as “Understanding people’s needs and pain points,” “Assessing the performance of a solution from my stakeholder’s perspective,” “Negotiating with team members from other disciplines,” and “Becoming more open-minded to alternative point of views” were among the least-improved

skills. These results indicated that students valued technical and problem-solving skills the most among the learning outcomes of the ICPs. This finding is contradictory to the results of the topical analysis, which showed a growing relationship between ICPs and innovation and entrepreneurship-related learning outcomes. Technical and problem-solving skills are critical for the formation of engineers, but more is needed to prepare engineers to make a change. Engineering students must understand how their solutions create value and for whom (Steiner, 1998).

Although two of the top three most-improved skills/abilities were identical, we also observed slight differences between the two universities regarding innovation and impact-related skills. The skills/abilities related to the impact stage in the EML Framework include expressing an engineering solution in economic terms, communicating solutions to various stakeholders, validating market interest in the solution, and understanding its societal and environmental impacts. As seen in Figure 4 and 6, the students in University II ranked “Advancing networking and social skills” and “Assessing the performance of a solution from my stakeholder’s perspective” higher and ranked “Learning through trial and error” lower than those in University I. This trend can also be observed in the regression coefficients given in Table 3 and the aggregated results in Table 4. These findings could be explained by differences in the scope and focus of ICPs that the universities offer. As discussed before, students in University II reported participating in many different ICPs, including programs directly related to engineering entrepreneurship. In contrast, students in University I reported a lower variety of programs with a more technical focus.

Table 4 shows that students from University II rated the impact-related skills/abilities more improved than students from University I. However, despite this difference between the two universities regarding impact-related skills, we observed that both Universities showed the same pattern regarding the effect of ICP type on the ratings of the skills/abilities (research question R2). In both universities, the participants of solution-focused ICPs ranked “Learning new technical skills and knowledge” ($\beta_{Type} = -0.50$) and “Learning through trial and error” ($\beta_{Type} = -0.40$) lower than those of technical-focused ICPs. Instead, the participants of solution-focused ICPs ranked impact-related skills “Assessing the performance of a solution from my stakeholder’s perspective” ($\beta_{Type} = 0.40$), “Understanding people’s needs and pain points” ($\beta_{Type} = 0.51$), and “Communicating a solution to various stakeholders” ($\beta_{Type} = 0.40$) higher than those of technical-focused ICPs. When we analyzed the individual student responses, we observed this pattern in both universities. In University I, 69% of the technical-focused group rated “Learning new technical skills and knowledge” as the most-improved skill/ability, while 40% of the solution-oriented group did so. Respectively, these ratios were 60% and 16% for University II. Instead of technical skills/abilities, the solution-oriented group in University I more frequently rated “Assessing the performance of a solution from my stakeholder’s perspective” and “Understanding people’s needs and pain points” among the most-improved skills/abilities. The respective ratios for these two skills were 5% (technical-focused) versus %11 (solution-focused) and 0% (technical-focused) versus %10 (solution-focused). Note that students in University II already had a relatively higher ranking for these skills/abilities. The respective ratios for these two

skills/abilities were 20% (technical-focused) versus 36% (solution-focused) and 12% (technical-focused) versus 28% (solution-focused) in University II. The aggregated analysis of the skills/abilities in terms of the three components of KEEN’s EML in Table 4 also supported that the participants of the solution-focused ICPs more frequently ranked impact-related skills/abilities as the most-improved compared to the participants of technical-focused ICPs did ($\beta_{Type} = 0.218$ with p -value=0.049 and $\beta_{Type} = 0.237$ with p =0.063 for University I and II, respectively). On the contrary, the participants of the technical-focused ICPs more frequently ranked designed-related skills/abilities as the most-improved compared to the participants of the solution-focused ICPs did ($\beta_{Design} = -0.207$ with p =0.033 and $\beta_{Design} = -0.460$ with p =0.00 for University I and II, respectively).

In summary, our findings support that ICPs can foster innovation skills at a higher level if they incorporate entrepreneurial concepts more. ICPs can incorporate impact-related skills/abilities by encouraging students to develop solutions that are not only technically innovative but also marketable and scalable. Students participated in solution-focused ICPs ranked “Communicating a solution to various stakeholders,” “Understanding people’s needs and pain points,” “Assessing the performance of a solution from my stakeholder’s perspective,” and “Becoming more open-minded to alternative points of view” persistently higher than students who only participated in technical-focused ones. Another approach to foster impact-related skills/abilities is encouraging competition teams to validate their designs and solutions with target customers through customer interviews. Faculty mentors can also play a critical role in guiding students in validating their solutions’ market viability. Integrating stakeholder engagement in ICPs can also foster impact-related skills/abilities (Zogaj, Kipp, Ebel, Bretschneider, & Leimeister, 2012).

Related to research question R3, the demographic variables had no statistically significant effect on most of the skills/abilities and challenges, as shown in Table 3. The only common pattern between the two universities was the effect of gender on “Advancing networking and social skills”. Comprehensive empirical studies on the perceived ICP experiences of female and male students are limited in the literature. Some studies suggest that female students had a negative experience with competitive pressure at hackathons, as discussed in the background section. However, this was not observed in our overall data on ICPs. Both female and male students had similar patterns of rankings for all items, excluding “Advancing networking and social skills,” that female participants more frequently ranked higher compared to male students in both universities ($\beta_{gender} = 0.49$). In Universities I and II, respectively, about 27% and 37% of female students indicated “Advancing networking and social skills” among their most-improved skills/abilities compared to only 7% and 31% of male students. An earlier study Hardin (2021) also reported that female students were more open to collaborating with other students whom they were unfamiliar with in student competitions. Networking and socialization motivate students to participate in these events (Warner & Guo, 2017), and solutions-focused ICPs also tend to engage more female students (Dzombak, Mouakkad, & Mehta, 2016; Mehta, Zappe, Brannon, & Zhao, 2016). In light of earlier research, our findings suggest that emphasizing the social aspects of ICPs may encourage more female students to participate.

In terms of challenges (research question R4), students most frequently indicated “time management,” “not knowing how to approach the problem,” “ambiguity and uncertainty,” “coming up with a solution,” and “lack of technical knowledge and skills,” with very close frequencies in both universities. Time management was the most frequently mentioned challenge in both universities. ICPs are typically time-demanding activities. On top of that, the requirements of engineering curricula leave students with minimal time to participate in co-curricular activities and take on other responsibilities. The lack of time has been reported as a significant barrier to the participation of students in ICPs (Kulturel-Konak, Konak, et al., 2023; Pan et al., 2015). To increase the involvement in ICPs, universities may consider organizing ICPs with a limited time commitment and targeting students at their universities early in their education when they typically have more time available. For example, low-stake ICPs could be a part of students’ first-year engineering experience. This intervention can also introduce students to engineering skills across the whole spectrum of the KEEN EML Framework early in their education. Academic programs could encourage ICP participation to meet educational requirements, which could then justify faculty time spent advising ICPs.

After “time management”, the students rated “Lack of technical knowledge and skills,” “not knowing how to approach the problem,” “ambiguity and uncertainty,” “coming up with a solution,” among their top most-experienced challenges. This outcome indicated that ICPs challenged the students’ innovation skills through open-ended problems. These challenges can be overwhelming, but they also provide valuable learning opportunities. Supporting ICP participants with the necessary help and guidance is crucial to prevent these challenges from becoming stressful. Too much competitive pressure can reduce participants’ creativity in open-idea challenges (Hofstetter et al., 2021). Offering support through coaching, mentoring, workshops, and training can help reduce students’ unnecessary anxiety due to lack of skills (Nolte et al., 2020) and help them acquire the skills and knowledge essential for innovation. Making expectations, judging criteria, and rules up front and clear is also important to mitigate unnecessary ambiguity and reduce the time for students to navigate issues (Konak, Kulturel-Konak, Schneider, & Mehta, 2023). In this study, ICP Type had a significant effect on “competitive pressure” ($\beta_{Type} = 0.48$) and “communicating a solution to various stakeholders” ($\beta_{Type} = 0.40$). Overall, participants of solution-focused ICPs were more concerned with these two challenges. Finally, participants from non-engineering majors had concerns about “Finding a mentor” ($\beta_{Type} = -0.33$).

Although “not feeling a sense of belonging” was one of the lowest-ranked challenges experienced, it needs more attention. About 13% of respondents in University I and 14% in University II indicated that they experienced “not feeling a sense of belonging”. About 60% of the upper-level students stated that this was among the least experienced challenges in both universities, but only 40% and 48% of lower-level students did so. The observed stronger sense of belonging in students who are at higher-level class standing is somewhat expected as first and second-year students are still adjusting to the environment and may find it harder to connect socially or navigate academically (Morosanu, Handley, & O’Donovan, 2010). A sense of belonging is important for students’ academic success (Strayhorn, 2018), professional development,

and mental health. ICPs can be a part of a solution for fostering engineering identity and belongingness in new engineering students by providing them with opportunities to work together in groups and support one another through a common objective. For example, design projects have been shown to increase electrical and computer engineering students' engineering identity and belongingness (Rohde et al., 2019). However, engaging students in ICPs alone will not establish a sense of belonging. As fostering belongingness requires intentional and persistent support (Verdín, 2021), ICPs should provide a welcoming environment for all students, including inclusive messaging, rules and policies, opportunities to reflect on their experiences, and effective mentoring.

5 Limitations and Further Research

While interpreting the results, the limitations of the empirical study should be considered. In this study, the questions used were based on ranking, which means that students were asked to compare the items based on their level of importance or preference. It should be noted that low-ranked items do not necessarily indicate that the students did not improve those particular skills/abilities or experience the related challenges. The ranking scheme used is a way to measure the perceived importance of each item. To reduce the cognitive load, the participants were not expected to rank the selected items in the least category. Another important point to consider is that only a small percentage of students, who are usually self-motivated, tend to participate in ICPs. This means that the survey results may be representative of only some of the student population and should be interpreted with caution. However, the data collected from the survey can still provide valuable insights into students' perceptions and help identify interventions to improve student learning outcomes and experiences in ICPs.

Another limitation of our study is the potential inadequacy of our data set in fully addressing research question R3, which examines the factors affecting student innovation mindset-related outcomes and experiences in ICPs. The survey items primarily focus on the skills/abilities that students learned rather than directly assessing their mindsets. We map these skills/abilities into Kern Entrepreneurial Engineering Network (KEEN)'s Entrepreneurially Minded Learning Framework (Wheadon & Duval-Couetil, 2016), which is also skills/abilities-based. This focus limits our ability to infer detailed insights into the students' innovation mindsets, which include other dimensions Konak, Kulturel-Konak, and Liu (2023). The survey did not include specific questions targeting the nuanced experiences and mindsets of different demographic groups, making it challenging to infer how these groups experienced ICPs accurately.

6 Conclusion

Both our systematic literature review and empirical results demonstrated that student innovation competitions and programs (ICPs) are instrumental in fostering an innovation mindset among students. These co-curricular activities enable students to acquire new technical skills, apply classroom learning in practical settings, and develop entrepreneurial skills. The topical analysis indicated a growing relationship between

ICPs and innovation and entrepreneurship-related learning outcomes. However, our findings revealed that participants in technical-focused ICPs may not fully embrace impact-related innovation skills.

It is recommended that ICPs incorporate more entrepreneurship concepts to enhance their effectiveness in building an innovation mindset. This includes designing compelling value propositions, understanding people’s needs and problems, and considering the societal implications of their solutions. Integrating these elements can better prepare students to create value and drive positive change in society, business, and technology. Given these findings, further investigation into the impacts of ICPs on cultivating an innovation mindset is necessary. Future research should explore how different types of ICPs can be optimized to balance technical and impact-related skills, ensuring that students are well-equipped to innovate and address complex challenges in diverse contexts.

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Declarations

This research project was determined to be exempt from review by the Pennsylvania State University Institutional Review Board (IRB No: STUDY00018039) as it posed minimal risk to participants.

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