Fostering Innovation Mindset through Student Innovation Competitions and Programs

Abstract

Innovation Competitions and Programs (ICPs), such as design challenges, hackathons, startup incubator competitions, boot camps, customer discovery labs, and accelerator programs, are informal learning experiences that supplement the formal education of Science, Technology, Engineering, and Mathematics (STEM) students. As learning dynamics are shifting toward becoming more personalized, location-unbounded, and spontaneous, informal learning is also becoming increasingly important for achieving the broader objectives of STEM education. ICPs are important in educating the next generation of innovators, and they serve as a gateway to innovation and entrepreneurial ecosystems in many colleges. The current literature provides limited quantitative and qualitative evidence on student learning because of participation in ICPs. This paper summarizes the findings of a study to investigate the learning and experiences of students who participated in ICPs. The results showed that overall, students rated technical and problem-solving skills higher than some innovation mindset skills, such as understanding people's needs and pains. Furthermore, the results demonstrated relationships among student backgrounds, learning experiences, and ICP types. Findings suggested that incorporating more entrepreneurial elements in ICPs may improve the innovation mindset learning outcomes of ICPs.

Keywords: Innovation Competitions and Programs, Student Learning Outcomes, Innovation Mindset

Introduction and Background

STEM education literature often mentions students' experiential learning experiences in college settings and their roles in curricular interventions. In particular, student innovation competitions have long been essential to STEM education [1]. Research suggests that student competitions provide many benefits and experiences: experiencing teamwork [2], peer interactions and leadership, promoting creativity [3], gaining self-efficacy and enthusiasm, building a growth mindset, working on real-world applications, accessing informal mentorship, and connecting with employers [4-6]. It is crucial to practice some skills, such as leadership within a technical domain, and participation on an engineering competition team is a popular activity in this regard [7].

Another objective of student competitions is to foster an entrepreneurial and innovative mindset among engineering students. A mindset is a set of attitudes, behaviors, and beliefs that determine how individuals establish and pursue goals, their likelihood of achieving those goals, and how they react to challenges they encounter [8]. In a more extensive sense, an entrepreneurial mindset is characterized by the attitudes and behaviors commonly seen in entrepreneurs. According to Ireland *et al*. [9], an entrepreneurial mindset is "the ability to quickly detect, act, and mobilize, even in unpredictable situations." The Kern Entrepreneurial Engineering Network (KEEN) defines the entrepreneurial mindset with three components: curiosity, connections, and creating value, also known as the "3Cs." After an extensive literature survey, London *et al.* [10] defined a framework comprising 12 attitudes and 17 behaviors that align with the 3Cs.

Parallel to the entrepreneurial mindset, we can define an innovation mindset 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 et al.'s conceptual model of innovativeness [11] includes constructs such as knowledge, skills, and abilities, while the innovation mindset emphasizes dispositions, attitudes, and propensities [12]. Couros [13] describes eight characteristics of an innovator's mindset: empathic, problem finders/solvers, risk takers, networked, observant, creators, resilient, and reflective.

This paper investigates the role of student ICPs in developing students' innovation mindset from the perspective of students. While the number of academic publications about student competitions has grown recently, most of these papers focus on introducing competitions with limited data on student learning outcomes related to an innovation mindset. In this paper, we present findings from an empirical study to investigate the benefits of ICPs. The primary contribution of this paper is to gain a more comprehensive understanding of the benefits that students perceive during ICPs and how ICPs can be better designed to foster an innovation mindset.

Student Innovation Competitions and Their Benefits

Most of the published literature on competition-like challenges and competitions introduced competitions and summaries of student projects [14-20]. These studies usually concluded that competition-like challenges and competitions positively affect participants, as summarized by Kulturel-Konak [21]. Additionally, an increasing number of higher education institutions organize competition-like challenges to attract students to work on innovative projects. This increased interest in ICPs is illustrated by Figure 1, which presents the number of journal or conference proceedings publications indexed by the Web of Science since 2001. The number of publications exponentially increased from 2001 to 2019. It went down in 2020 when many institutions canceled their extracurricular activities or conducted them virtually due to the COVID-19 pandemic. The frequency for 2022 could be too early to be compiled when this analysis was performed.

We performed a topical analysis of the publications. The main objective of this topical analysis is to investigate the focus areas and expected student learning outcomes of these ICPs. The dataset for the topical analysis was obtained from the Web of Science by performing a topic search using the terms "hackathon," "student competition," "student contest," or "pitch competition," or its derivatives considering only STEM fields since 2001. Preliminary data cleaning involved deleting duplicate records, and publications without keywords, opinion pieces, and news articles. The final data set included only journal articles and conference proceedings. Initially, 1139 keywords were extracted from 501 publications. We post-processed the keywords by replacing similar words with the same keyword (e.g., replacing *contest*, *contests, international student competition*, *competitions* by *competition*) or merging terms into broader concepts (e.g., merging *machine learning* and *deep learning* into *artificial intelligence*). However, we limited the number of keyword mappings to reduce subjectivity.

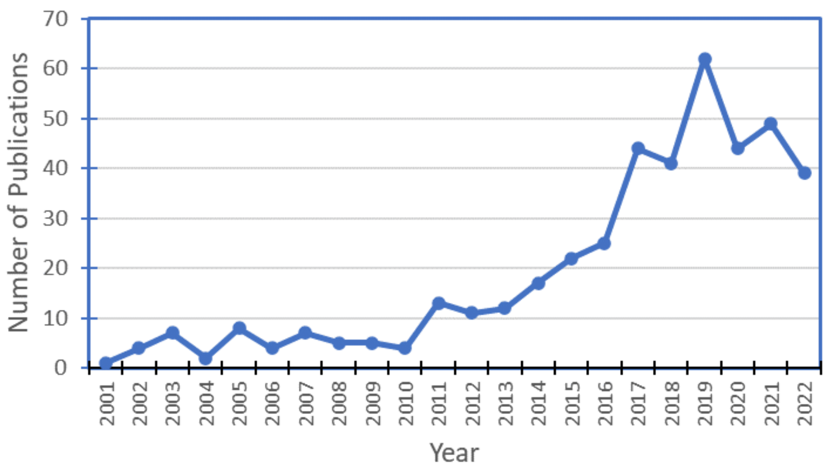

Figure 1. Frequency of publications (Web of Science) related to ICPs.

We used the merged keywords that occurred more than four times and clustered them according to how frequently they cooccurred in the publications. Figure 2 illustrates how 59 final keywords clustered into the six groups based on the frequency with that they occurred together as a cluster density plot. In Figure 2, the keywords' sizes indicate their occurrence frequency. The keywords that occurred together are located nearby compared to those that did not. For the clarity of network presentation, the links were not plotted. In the literature review section, we omit the citations of the publications unless they explicitly discuss the concepts and themes emerging in our analysis.

The cluster analysis identified two large clusters formed around the two most frequent keywords: *hackathon* and *competition*, as indicated by the green and blue clusters in Figure 2. These two keywords group together with different topics of ICPs. The term *hackathon* was associated with the terms *app development*, *participatory design*, *capstone*, *smart city*, *community* in the green cluster, *software*, *artificial intelligence, cyber security* in the red cluster, and *healthcare*, *open source* in the light green cluster, and the term *competition* was more frequently associated with the terms *vehicle*, *Formula SAE*, and *robotics* in the blue cluster. In a sense, the term *competition* appeared to be more frequently used in the context of traditional student engineering competitions that require project-based, long-term engagements, such as Formula SAE, Mini Baja, Robotics, and other vehicle design competitions. Interestingly, the keywords *project-based learning*, *active learning*, and *experiential learning* were more frequently associated with the term *competition.* In contrast, the terms *informal learning* and *collaborative learning* were more strongly linked to the term *hackathon*. Based on these observations, we can argue that ICPs support student learning by providing experiential learning opportunities outside the traditional classroom setting.

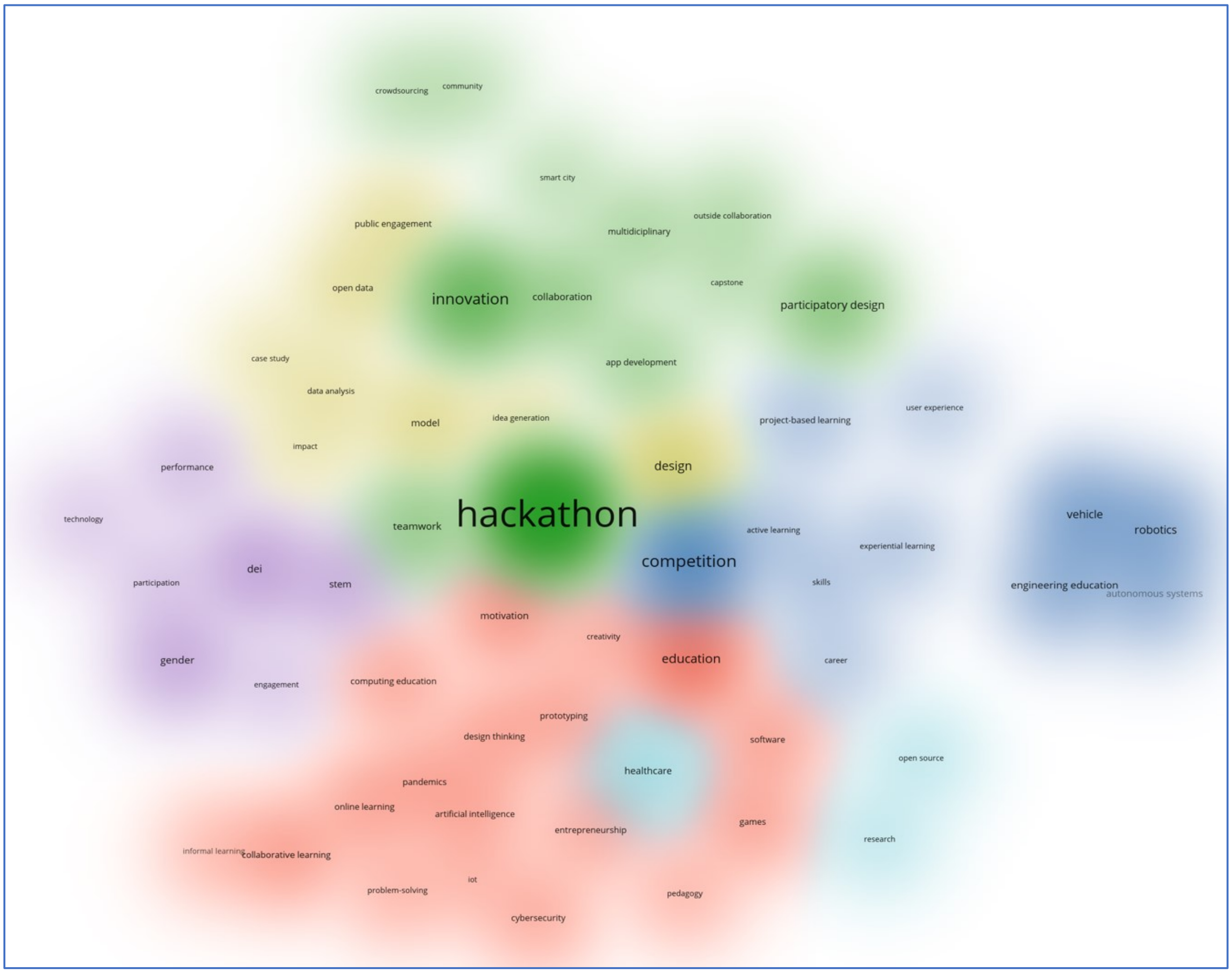

Figure 2. Cluster density plot of the extracted keywords.

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 purple cluster in Figure 2. Particularly, the terms *DEI* and *gender* were strongly connected to the term *hackathon*. Two contradictory phenomena could explain this strong relationship. Firstly, some hackathons specifically aimed to recruit females and other underrepresented students into STEM programs [22]. Secondly, many papers indicated barriers to and challenges ensuring diversity in hackathons [14, 23-27]. For example, our analysis showed weak associations between the *DEI/gender* cluster and *competition* cluster that represents more traditional engineering student competitions. Although concerns related to DEI issues were raised in the literature [28-31], strategies for enhancing diversity in ICPs still need to be explored. Currently, a very small percentage of underrepresented students participate in ICPs [14, 26, 27, 32, 33]. ICPs are an integral part of higher education innovation and entrepreneurial ecosystems to make students interested in innovation and entrepreneurship and help them build entrepreneurial mindsets [34]. In our analysis, the terms *entrepreneurship*, *idea generation, design thinking, prototyping, and problem-solving* were clustered together (in the red cluster) and strongly linked to the term *hackathon.*

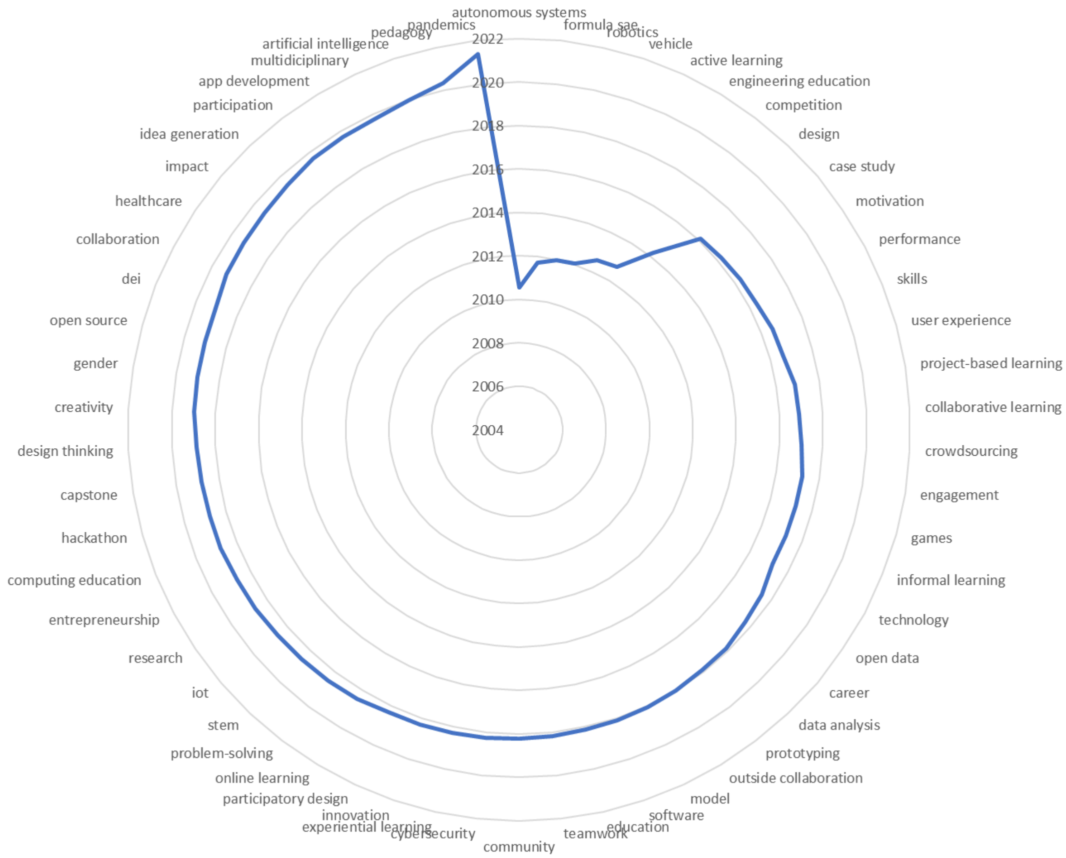

Figure 3. Average citation age of keywords. (The circle's center represents 2004, and the outer circle represents 2022.)

Another way ICPs promote innovation is by introducing students to processes or toolboxes of innovation and providing practices for critical thinking skills [35, 36]. ICPs engage students in further design activities and enable them to apply their classroom learning [6, 37]. In our analysis, the terms *design thinking*, *prototyping*, *problem-solving*, and *creativity* were clustered together and linked to the term *hackathon*. Learning the innovation process can help students build innovative/growth mindsets [34]. In addition, ICPs enable students to raise seed capital to bring their ideas to the marketplace [38].

Our analysis showed that ICPs increasingly incorporate entrepreneurship concepts as keywords related to innovation and entrepreneurship frequently appear in recent years' citations. In Figure 3, we plot the average citation of the extracted keywords. The terms such as *multidisciplinary*, *idea generation*, *impact*, *design thinking*, *entrepreneurship*, and *innovation* had an average citation age higher than 2018, indicating some of the trends in ICPs. Practicing teamwork and collaboration skills has been noted as another beneficial learning outcome of ICPs [4-7]. In our analysis, *teamwork*, *collaboration*, and *multidisciplinary* were grouped with and linked strongly to the hackathon term. We also observed another trend coined by the term *outside collaboration*, representing merged keywords such as *community engagement*, *industry collaboration*, *public collaboration,* etc. These terms also appeared in recent years, indicating ICPs play a growing role in engaging students in their local communities and industry projects. Top employers, particularly those in information technology fields [38], support or co-organize ICPs to identify and recruit talented students. Thereby, ICPs allow students to network with employers that are otherwise not easy to reach [4-6, 38].

Methodology

Procedures and Participants

A survey instrument was designed and sent to engineering students who participated in ICPs at a target institution. The survey had the following sections. The first group questions asked students their motivations for participating in ICPs using questions based on the value-cost model given in [39]. In the second group of questions, students were asked to select and rank three skills/abilities they developed the most due to participating in ICPs among the skills/abilities given in Figure 4. Subsequently, the students were instructed to select (ranking was not required) up to three skills/abilities that they developed the least among the given skills/abilities. The survey concluded with demographical questions. Students were invited to participate in the survey via emails or campus signage. Participation was voluntary.

Analysis of Student Responses

Since the students were asked to select and rank the given items of skills/ability, statistical analyses focused on evaluating the consistency of selections. Figure 4 provides the percentage of respondents (n=144) who ranked the skills/abilities as their three most improved and the three least improved ones in descending order according to the most improved ones. We evaluated the consistency of the ranks of the items in the most and least groups using Kendall's tau-b. The Kendall's tau-b correlation between the ranks of the items in the most and least improved categories was -0.481 (p-value=0.032) for the skills/abilities. This statistically significant, negative correlation suggested that the rankings of the items were consistent across the most- and least-improved categories. In other words, if an item was ranked high in the most-improved category, then the item should be ranked low in the least-improved category.

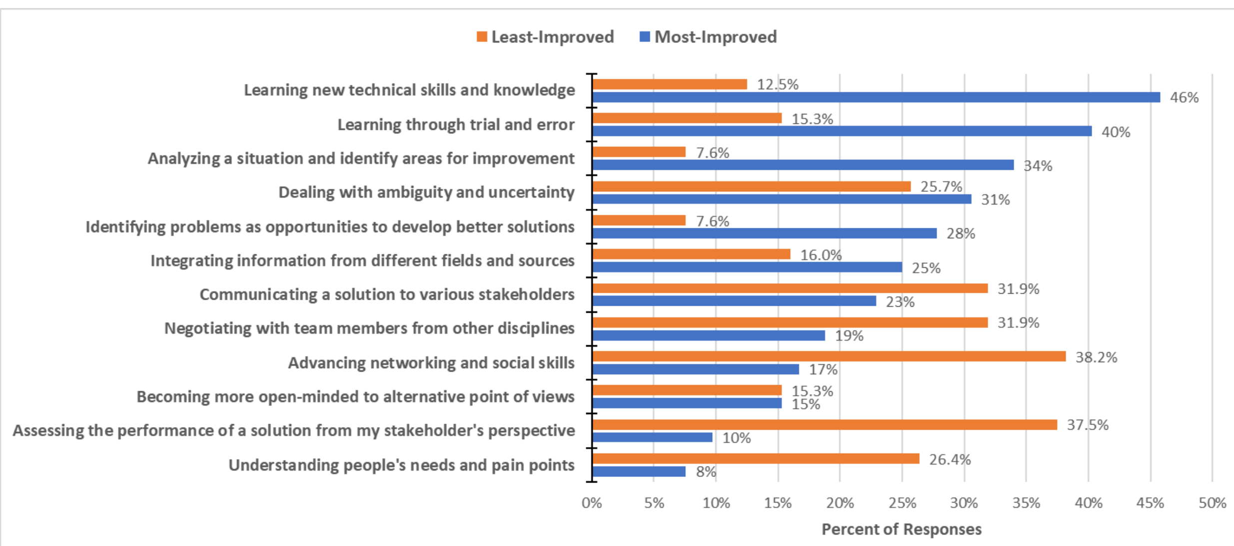

Figure 4. Students' responses to the most and least improved skills due to the ICP participation (n=144).

Discussions

As shown in Figure 4, the respondents more frequently selected "*Learning new technical skills and knowledge," "Learning through trial and error," and "Analyzing a situation and identifying areas for improvement"* among their top three most improved skills/abilities compared to the other items. These results indicated that students valued technical and problem-solving skills the highest among the learning outcomes of the ICPs they participated in. The respondents rated impact-related skills, "*Assessing the performance of a solution from my stakeholder's perspective*," and "*Understanding peoples' needs and pain points*" lowest among the most improved skills. Clearly, technical and problem-solving skills are critical for the formation of engineers, but they alone are not enough to prepare engineers to make a change. Engineering students need to understand how their solutions create value and for whom. Students do not normally value these skills as much as they are not valued in most of their traditional classes. Hence, even if they are given exposure to them by ICPs they are essentially ignored as they do not fit what students identify as skills needed for success, and students aren't evaluated on these skills directly in the vast majority of their academic experiences.

To better present student rankings trends, we categorized the skills/abilities into three stages of engineering skill sets, *Opportunity*, *Design*, and *Impact* according to the Entrepreneurially Minded Learning (EML) Framework [40]. We calculated an importance index for each skill/ability by taking the difference between how many times students listed them as the most improved and least-improved ones. This importance index indicates how much students value the skills/abilities that they gained during ICPs. Figure 5 illustrates the average importance index in each stage of the EML Framework. Clearly, the students ranked the skills/abilities related to the design stage as more valuable than the other stages. The skills/abilities related to the impact stage received a negative score, indicating that they were more frequently ranked as least-improved than most-improved.

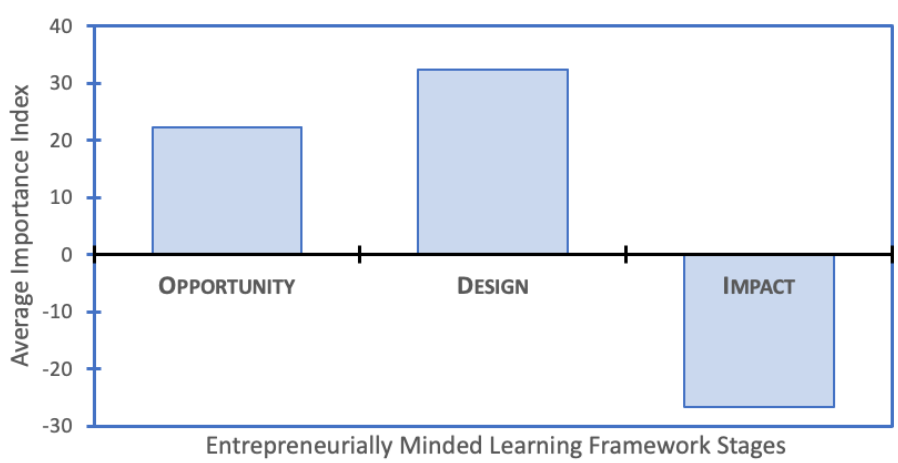

Figure 5. Students valued skills/abilities mapped to the Entrepreneurially Minded Learning (EML) Framework.

To increase participation in ICPs, higher education institutions may consider organizing ICPs with a limited time commitment and targeting students at their institutions 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 EML Framework early in their education.

Conclusion

Our systemic literature review and empirical results showed that student innovation competitions and programs are instrumental in fostering an innovation mindset among students. These extracurricular programs allow students to learn new technical skills, practice classroom learning, and develop entrepreneurial skills. To increase the impact of ICPs on building an innovation mindset, ICPs may incorporate entrepreneurship concepts such as designing compelling value propositions, understanding people's needs and problems, and the societal implications of their solutions. Therefore, further investigation of the impacts of ICPs on cultivating an innovation mindset is necessary. In addition, the challenges that students face during these ICPs need to be analyzed.

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