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Fostering Innovation Mindset through Student Innovation Competitions and Programs

Dr. Sadan Kulturel-Konak, Pennsylvania State University, Berks Campus

Sadan Kulturel-Konak is a Professor of Management Information Systems and the Director of Flemming Creativity, Entrepreneurship and Economic Development (CEED) Center at Penn State Berks. Dr. Kulturel also has a courtesy appointment at Penn State Harold and Inge Marcus Department of Industrial and Manufacturing Engineering. She received her Ph.D. in Industrial and Systems Engineering from Auburn University. Dr. Kulturel's research focuses on modeling and optimizing complex systems using hybrid approaches combining heuristic methods and exact techniques from probability and operations research. The primary application areas of her research include designing and redesigning facilities to provide significant economic benefits for the US industries. Dr. Kulturel is also interested in pedagogical research regarding entrepreneurship/STEM fields, such as professional skill development, innovative thinking skills, and gender differences in learning styles. She served as the President of the INFORMS-Women in OR/MS (WORMS), the Chair of INFORMS- Facility Logistics Special Interest Group, and the Chair of the ASEE Middle Atlantic Section. She is currently an academic member of the College Industry Council on Material Handling Education (CICMHE). She is an Associate Editor of the Engineering Applications of Artificial Intelligence (Elsevier). She has been a principal investigator in several sponsored projects from National Science Foundation (NSF) and VentureWell.

Dr. Abdullah Konak, Pennsylvania State University, Berks Campus

Dr. Abdullah Konak is a Distinguished Professor of Information Sciences and Technology at the Pennsylvania State University, Berks. Dr. Konak also teaches graduate courses in the Master of Science in Cybersecurity Analytics and Operations program at the College of Information Sciences and Technology, Penn State World Campus. Dr. Konak's primary research interest focuses on modeling, analyzing, and optimizing complex systems using computational intelligence combined with probability, statistics, data sciences, and operations research. His research also involves active learning, entrepreneurship education, and the innovation mindset. Dr. Konak's published numerous academic papers on a broad range of topics, including network design, system reliability, sustainability, cybersecurity, facilities design, green logistics, production management, and predictive analytics. He has been a principal investigator in sponsored projects from the National Science Foundation, the National Security Agency, the U.S. Department of Labor, and Venture Well.

Prof. David Robert Schneider

David R. Schneider graduated from Rensselaer Polytechnic Institute in chemical engineering in 1999, attended Columbia University Film M.F.A. Program in 2001, and earned his master's and Ph.D. from Cornell University in mechanical engineering with a concentration in controls & dynamics in 2007. David has taught at both Columbia University, where he was the highest student-rated instructor in the College of Engineering, and at Cornell University where he is now the Director of M.Eng. Studies for Systems Engineering, the largest M.Eng. program at Cornell.

As a faculty member in systems engineering, David has focused largely on industry collaborations, advising over 1200 professional M.Eng. students, and over 1000 students overall on student projects with companies and government agencies that have ranged from Intel, Lockheed Martin, ARM, Carrier, US Green Building Council (USGBC), Applied Materials, MOOG, SRC, Altera, Boeing, Smithsonian, Hasbro, Autodesk, MathWorks, L-3, MITRE, Da Vinci Labs, JPL, Air Force Research Labs, Marine Corps, NSF, M-E Engineers, NASA Ames, Goddard, & Kennedy, and more, where most projects have lead to real world implementations and/or are being developed with Cornell Technology Licensing. Some of the David's favorites include:

* Creation of the Cornell Cup USA presented by Intel, now the Cornell Cup – Arm Enabled, international embedded systems competition * Cape Canaveral AFS / NASA Kennedy collaboration Minotaur Launch

Vehicle Feasibility Study, turning minotaur missiles into low orbit launch vehicles and leading to successful launch of the OSR-5 satellite * Unmanned Aircraft Evasive Maneuver Mission Re-planning Algorithm Development with MITRE * Taiwanese Disaster Recovery Plan Modeling with Lockheed Martin * New Product Development Process Re-design with Applied Materials * R2-D2-inspired Lab Assistant Droid and C-3PO-inspired Telepresence Walking Droid showcased to top members of the Obama White House Office of Science and Technology Policy, at NASA Kennedy Space Center, the NYC Hall of Science, and Walt Disney World

With a strong focus on education, David created the first experience in the world recognized by the systems engineering professional society INCOSE as knowledge exam equivalent, and the only person to have created now two experiences earning this honor. Additionally, David created and runs the systems engineering courses for Lockheed Martin's largest Engineering Leadership Development Program. David's main course, Model Based Systems Engineering, is also now officially sponsored by Boeing. David has also received multiple recognitions for his educational work from the Obama White House Office of Science and Technology Policy and was an invited guest for the official start to the National Week of Making and the CS4ALL initiatives. David also led the broader impacts video game creation for the NSF Expeditions in Computing Grant on Computational Sustainability and is the head faculty advisor for Cornell Cup Robotics and Cornell University Sustainable Design (CUSD), which is commonly Cornell's largest and most diverse student project team. David was also a screenwriter for Walt Disney Attractions Television Production.

Research Interests: David Schneider's research has traditionally focused on the realm of NP-Hard Computer Science Problems and Controls for Robotic Systems in both centralized & decentralized and autonomous & semi-autonomous systems. His most prominent research is his creation of the G*TA (G-Star-T-A) task allocation algorithm and his work as program manager of the Cornell RoboFlag program, with notable applications including AFRL UAV controls and NASA/NOAA unmanned boat designs. Aside from his work at Cornell, David also values his time dedicated to this area while at NASA Goddard as a team lead in Code 88 Advanced Automations & Architectures.

Most of David's career at Cornell has focused on collaborative projects and research with industry, or even in support of Cornell initiatives. Some of David's favorites include:

* Remote Occupancy Sensing HVAC controls system with M.E. Engineers Architectural consulting firm as well as recently Blackstone's $448,000,000,000 Global Real Estate Portfolio * Sunn Hybrid Lighting Project sighted as a top project in the nearly 20 year history of the EPA P3 grant and became a successful student start-up company * Cold Climate Greenhouse Research examining low energy and mixed aquaculture/hydroponics, which raised funding for the creation of new experimental greenhouse on Cornell's main campus, with a partnering world-wide 70 pilot site collaboration * Investigating novel sustainability and alternative energy generation options for the proposed Cornell Tech Campus on Roosevelt Island in NYC with CUSD and being the only student project group recognized and thanked by Cornell President Skorton in letter to the alumni on Cornell's ˜$500,000,000 Tech Campus proposal win over Stanford. Then being highlighted in the opening plenary talk of Greenbuild with USGBC CEO and President Rick Fedrizzi for related work. * Disney-Inspired Star Wars Pod Racing Theme Park ride with MOOG for the development of a VR plus 6DoF Motion Platform, cited as being the first successful combination of VR and a 6DoF motion platforms

David is also dedicated to STEM and particularly engineering education R&D since even his early career with publications in journals such as the International Journal of Engineering Education—Active Learning Special Edition and being the key developer of the broader impacts on grants like the NSF Expeditions in Computing Grant on Computational Sustainability. Stemming from his involvement in the Obama CS4ALL initiative, David also developed a means of assessing computer science educational programs against the Computer Science Teacher Association's K-12 standards as well as informing students, teachers, and parents on a student's computational thinking learning progression. David continues to be dedicated to this R&D area and has developed a computer science focused educational robot to rival Lego Mindstorms, Vex & MakeBlock that has been licensed thru Cornell Technology Licensing to Educational Technologies. Most recently, David is also a Co-PI on the NSF "Cultivating Innovative Thinking

Skills in STEM Education" grant investigating the education benefits of college student project teams and competitions.

Teaching Interests: David Schneider has dedicated much of his career towards the improvement of engineering education. In addition to mentoring typically over 200 students every semester on many of the projects listed above, David has taught courses such as Model-Based Systems Engineering, Engineering Project Leadership, and Creativity in Engineering. Through the Cornell Cup, David has also developed in conjunction with the Cornell team's students, a series of systems engineering professional design guides that target identified nationwide curriculum gaps. Utilizing this work in particular, students have earned such recognitions as being the 1st American team to win the James Dyson Award for Engineering Design, one of America's "30 Under 30", and even quoting the guides when being featured on NBC as one of the top six "College Inventions Everyone Should Be Aware Of".

These guides have been used by students and faculty around the world including from: U. Akron, ASU, Berkeley, Boston U., UC Davis, UC San Diego, Carnegie Mellon, U. Colorado Denver, Columbia, Duke, U. Florida, Florida Inst. of Tech, Georgia Tech, U. Houston, Howard, U. Illinois at Urbana-Champaign, John Hopkins, UMass Amherst, UMass Lowell, U. Michigan, MIT, Oklahoma State, Oregon State, UPenn, Penn State, U. Pittsburg, Portland State, Purdue, RIT, U. Rochester, RPI, Seattle Pacific, Southern Illinois University at Carbondale, Tufts, USC, Vermont Tech, Virginia Tech, WPI

David has received numerous recognitions for his work in this area, including recognition from the Obama White House Office of Science and Technology Policy where his work was cited as one of seven university efforts in the White House Fact Sheet of Making in 2015 and again in 2016 as one of nine university efforts out of 1,500 university and K-12 efforts seriously considered.

As a member of the Cornell Faculty Institute for Diversity, David also leads what is commonly the largest and most diverse student team on campus, Cornell University Sustainable Design (CUSD), as well as Cornell Cup Robotics, both of which are often led by a majority of female students.

David also co-founded the NASA Robotics Alliance Cadets program with Mark Leon, NASA AMES Director of Education and David Lavery, NASA Program Executive of Planetary and Solar Exploration. David has also served on a number of educational committees and panels including being a guest expert on the "America's Favorite Maker" TV show. David has led the efforts to make Cornell the first university to officially partner with Make:. With Make: David led the re-creation of the national entrepreneurial competition "Pitch Your Prototype". David also was the leading faculty member behind the American Society of Engineering Education, Community Engaged Division Film Festival national competition. As one who has always sought to embody Cornell's "Doing the Greatest Good…" initiative, David with Cornell Cup Robotics is also currently mentoring the Afghan Dreamers, the all-girls robotics team from Afghanistan, thanks to a collaboration with the Afghan Dreamers parent organization the Digital Citizen Fund.

Prof. Khanjan Mehta, Lehigh University

Khanjan Mehta is the inaugural Vice Provost for Creative Inquiry and Director of the Mountaintop Initiative at Lehigh University. Mehta champions the creation of integrated learning, research, and entrepreneurial engagement ecosystems where students, faculty, and external partners come together to increase their capacities for independent inquiry, take intellectual risks and learn from failure, recognize problems and opportunities and effect constructive and sustainable change. Mehta is the prime instigator for four signature academic programs – the Mountaintop Summer Experience, the Global Social Impact Fellowship, the Lehigh Valley Social Impact Fellowship, and the Campus Sustainable Impact Fellowship that engage faculty and students in ambitious, interdisciplinary, multi-year, impact-focused ventures.

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.

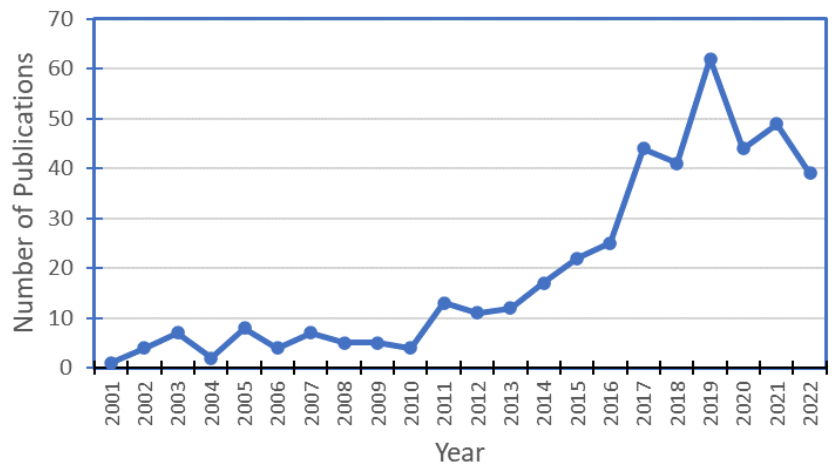

Figure 1. Frequency of publications (Web of Science) related to ICPs.

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.

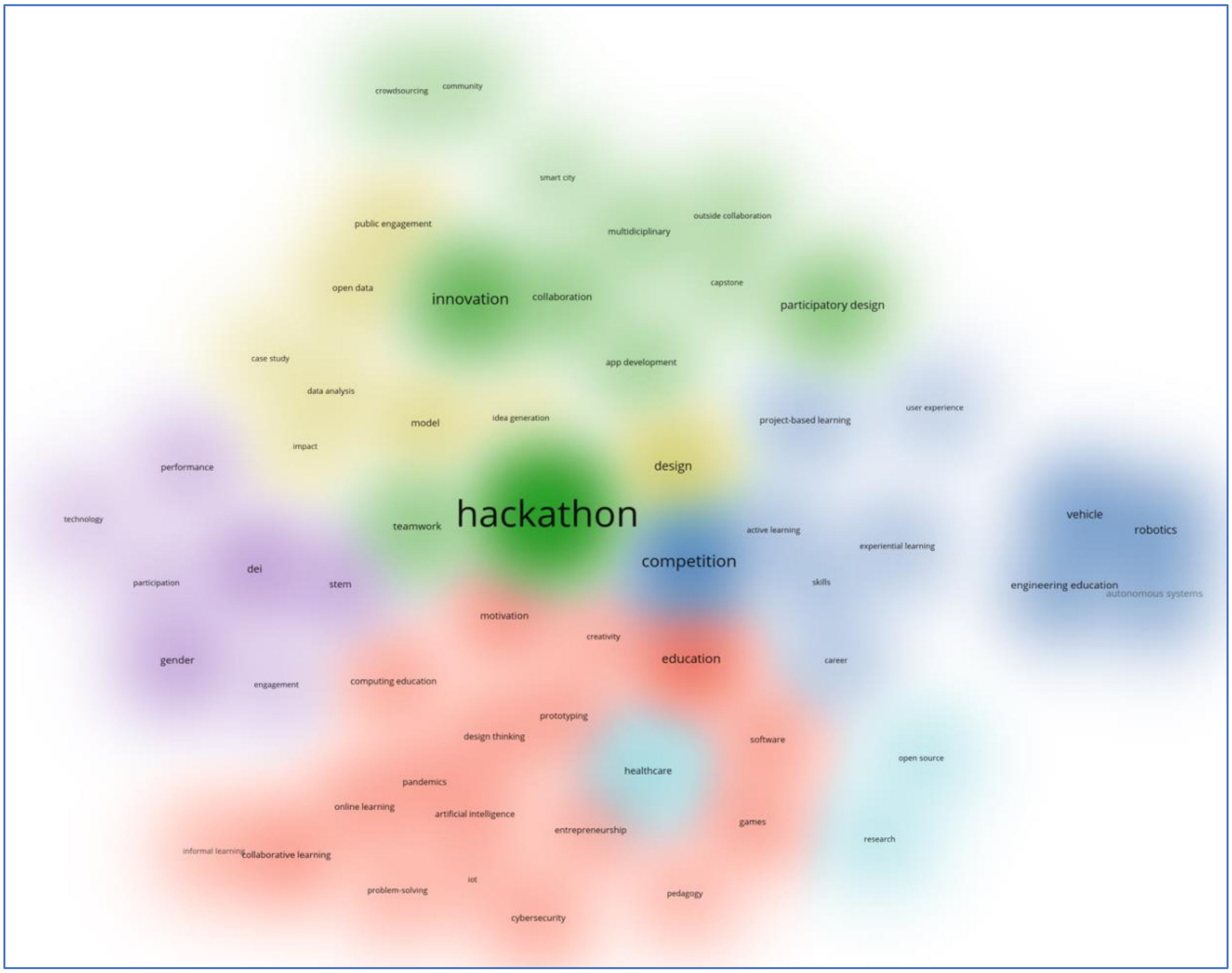

Figure 2. Cluster density plot of the extracted keywords.

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.*

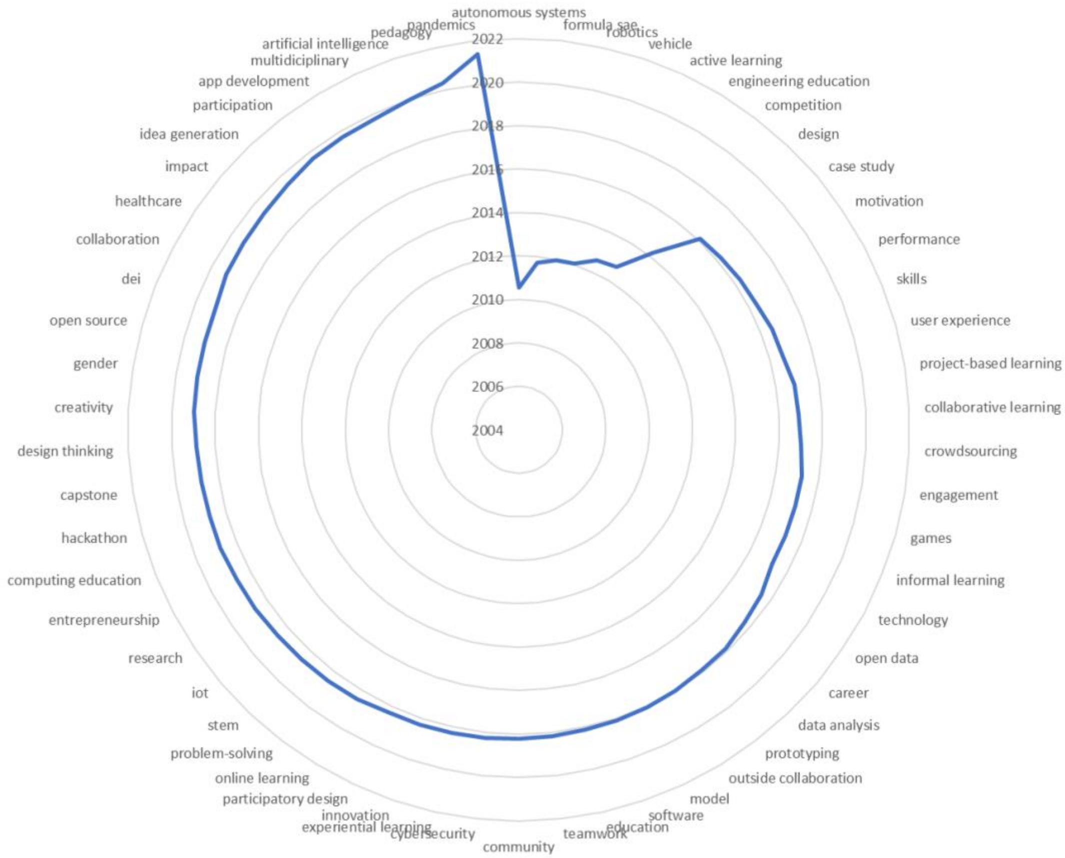

Figure 3. Average citation age of keywords. (The circle's center represents 2004, and the outer circle represents 2022.)

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.

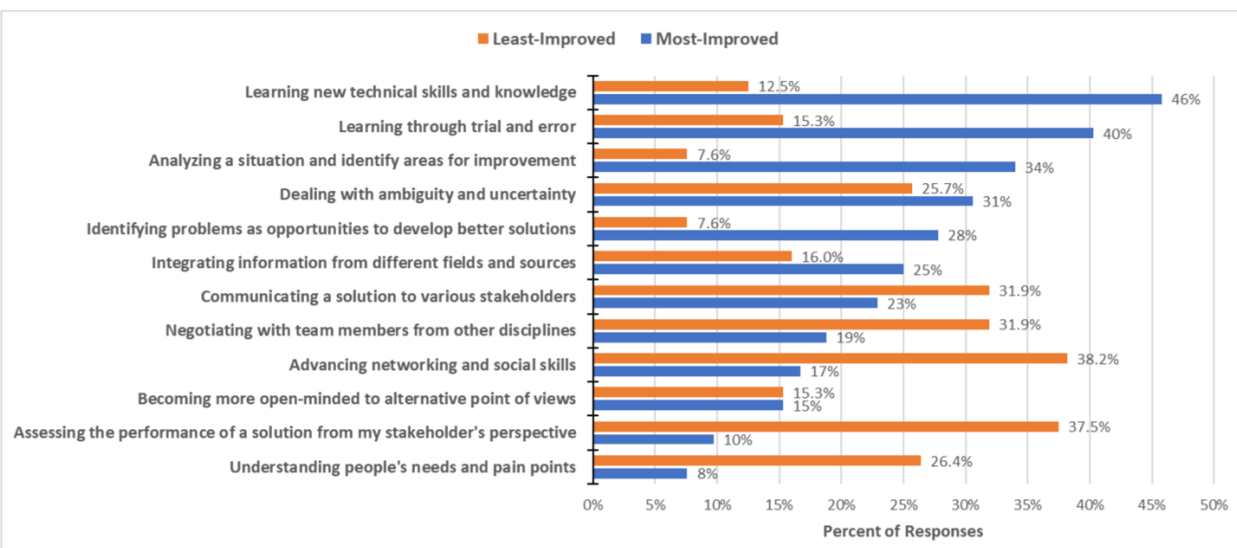

Figure 4. Students' responses to the most and least improved skills due to the ICP participation (*n*=144).

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.

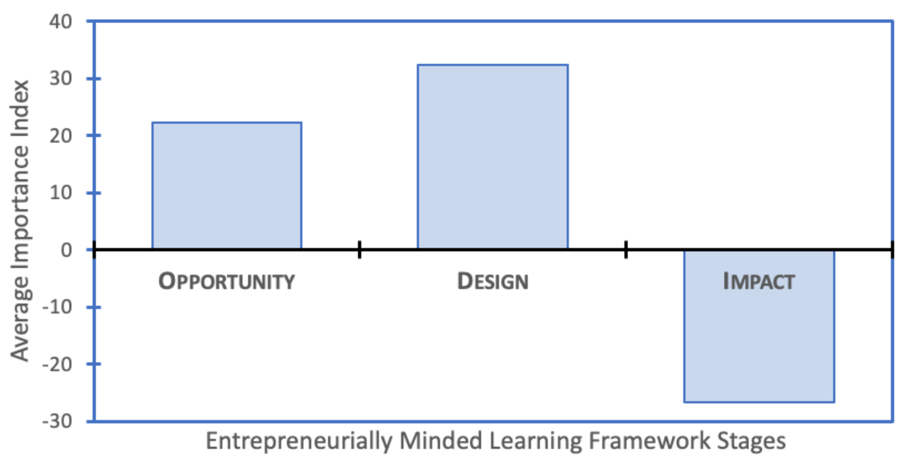

Figure 5. Students valued skills/abilities mapped to the Entrepreneurially Minded Learning (EML) Framework.

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.

Acknowledgment

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