Innovation Competitions in STEM Education: A Comprehensive Analysis of Attributes and Student Experiences

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Abstract - **In order to gain technical and professional experience, many students in STEM fields participate in extracurricular activities, called such as Innovation Competition and Programs (ICPs). ICPs can offer students a hands-on experience in their field, fostering creativity and entrepreneurship while also solving problems as a team. While the literature emphasizes the many benefits that ICPs offer and examples of different types, there is not yet a broad discussion of different ICP attributes, or many documented student testimonials. This paper aims to establish a precise categorization of the various attributes found in such programs and examine actual student ICP experiences to understand how to adjust these attributes in order to provide students with the most positive experience possible. It is helpful to outline the potential attributes of ICPs due to their open-ended and university-dependent nature. In addition, student interview data provides insight into the overall experiences that students have had when participating in these programs, allowing connections to be made between student goals and the structure of the programs themselves.**

Index Terms - Attributes, Entrepreneurship, Innovation Competitions and Programs, Student Experiences

INTRODUCTION

Many students within the Science, Technology, Engineering, and Mathematics (STEM) fields seek additional opportunities to expand their knowledge and experience in more "real-world" environments. These extracurricular activities, referred to as Innovation Competitions and Programs (ICPs), offer students a hands-on experience where they may develop crucial technical and professional skills. There are many different types of ICPs, including pitch competitions, hackathons, design challenges, entrepreneurship challenges, pitch competitions, and others.

Research exists to support the necessity of integrating these programs into STEM curriculum and highlights many benefits [1, 2]. Students may see advances in their professional or leadership development. Newell and Ulrich [3] find that STEM students are faced with two main challenges upon graduation: high competition in their field and employers being concerned that they lack general competencies and work experience. Experiential learning programs like ICPs aim to close this gap. McKenzie [4] suggests that student participation in these programs is linked to greater success rates, higher employment rates, increased firm entry, and greater profits and sales overall. Wolfinbarger et al. [5] conclude that participation in engineering competition teams enhanced the leadership identity development of most participants. Students participating in this innovation program improved both their technical competence and their knowledge and ability to lead. Hence, this can prepare students for their academic and professional lives, as well as future careers and post-graduation opportunities.

Russell et al. [6] state that when students prepare for a competition, such as a business plan competition, they gain discipline, industry-specific skills and knowledge, and business skills to develop a new product or service. Moreover, there is a need for enhanced experiences and curricula within STEM fields that allow for complex and innovative thinking. Hoeg and Bencze [7] report findings that only 6% of performance expectations in STEM classes described participatory practices, meaning students have the authority to explore what innovative methods or creative solutions could solve a problem. STEM students especially have identified a need for not only hands-on, participatory experiences but also ones that allow them to think outside the box and build their innovative mindset.

This paper presents the overall student experience with ICPs based on an analysis of interviews with 36 students who participated in various ICPs. In addition, we have documented common attributes of ICPs to better understand the connections between ICP attributes and student experiences.

LITERATURE REVIEW

Due to their perceived benefits and potential to enhance the STEM student experience, there has been an increase in the inclusion of ICPs in student learning, both inside and outside the classroom. In addition, many universities have established innovation hubs that spearhead ICPs at the college level. McNew [8] shares the success that Pittsburgh State University has found with their use of innovation competitions built into the engineering curriculum. Their collaboration with NASA's Rover Challenge allows engineering students to improve their design skills in a team-project environment. This curriculum has found success, with student teams placing in NASA's nationwide competition. More importantly, it was reported that the competition serves as a great teaching tool and gives students a competitive edge when searching for jobs in the future.

These hands-on experiences are beginning to spread across various disciplines, and Mufti et al. [9] found that when incorporating experiential learning into science curriculum, specifically when students were learning fluid dynamics, test scores increased significantly. Sarkar et al. [10] measured perceptions of experiential learning among students and faculty in anatomical sciences education and found that the satisfaction index of experiential learning-based sessions was 96.1% for students and 100% for faculty. These more hands-on tactics are producing higher academic achievement, and are also more engaging, interesting, and skill-building for students. Much evidence supports the notion that experiential learning and experiences in and out of the classroom have large impacts on students' ability to understand material and broaden their skill sets in many fields.

Batra and Milestone [11] also discussed the growing integration of business plan competitions into entrepreneurial curricula. These competitions are useful educational tools that may also launch start-ups that benefit the local and greater community. They report that the most standard format of a business plan competition includes student teams whose social enterprise business plan is evaluated by a panel of judges. Criteria may include projects most likely to succeed or most likely to create tangible social impact. These competitions offer vital skills, networking, and experience, and often cash prizes up to $1,000,000.

While some competitions involve large amounts of time, funding, and preparation, others are much smaller. Blair [12] discusses the success of including weekly pitch competitions in his marketing curriculum to improve necessary business and entrepreneurial skills among students. Students reported that the interactive assignments were both helpful and fun, supporting the need for hands-on experiences in both large and small programs.

In recent years, different formats of these competitions have been developed and implemented to support the health and safety needs of the COVID-19 pandemic. Douglass et al. [13] describe the challenge organizers faced with running pitch competitions while following CDC guidelines. Many institutions refrained from hosting these programs for a year but returned with new technology to provide students with experiential learning despite the health crisis. Douglass et al. found that despite much learning returning to normal in the classroom in the last two years, many pitch competitions still utilize virtual web conferencing technologies like Zoom. The pandemic has created a new attribute involving the nature of these programs, whether they are online or in person.

Some characteristics of student ICPs, as identified by Russell et al. [6], include mentorship, networking, prizes, entrepreneurial insight, skill-building workshops, and team building. Adamczyk et al. [14] classified student ICPs into the following general focuses or perspectives: an economic perspective, management perspective, education focus, innovation focus, and sustainability focus.

These attributes contribute to shaping the student experience in ICPs, influencing what they learn, what they create, and their opinions about the programs themselves. Student experience may vary based on the program they participate in. One negative piece of the student experience is time constraints. Lichtenstein et al. [15] analyzed student data and determined that engineering students spent significantly more time preparing for class than students in other majors. Engineering students are forced to choose between acquiring practical skills through their coursework and engaging in educationally enriching extracurricular experiences. Simmons et al. [16] later concluded that the engineering curriculum leaves little time for outside engagement and that there was a noticeable lack of extracurricular involvement compared to other majors. The student experience outside of these extracurricular programs is vital to consider when designing supplemental activities for already busy students.

Zapata-Ramos and Lugo [17] discussed a program looking to address students with busy schedules by incorporating business and engineering concepts into one project-based learning program. Students reported many positive outcomes after participating, including increased communication skills, a competitive edge when searching for jobs, experiences working on a team, improved technical skills, and an increased entrepreneurial mindset. If students can manage to add ICPs to their schedules, many report a positive experience and many benefits.

Seeking data about the student experience shaping perspectives, Stringer et al. [18] surveyed students about their perceptions of STEM careers before and after participating in STEM extracurricular activities. Females who participated in these programs reported having a stronger identity associated with a STEM career and more motivation to engage in science activities than those who had not participated. Well-designed ICPs can potentially increase the gender gap evident in STEM fields by empowering young women to be a part of innovative solutions.

Much research exists to support the necessity of ICPs in STEM learning. Testimonies of many different types of programs have also been shared, along with their perceived benefits and successes. However, there appears to be a gap in the literature regarding, more specifically, classifying these different types of competitions for STEM students. Additionally, aligning the structure and specific attributes of these programs with the perceived benefits and goals of students can more positively impact the overall student experience. This classification and the analyses of student experiences will provide insight into how to add value to the ICP experience to give students the best possible opportunities and curriculum that will contribute to their overall success.

CLASSIFICATION

Table I classifies different attributes of ICPs. Each attribute has several possible classifications. These classifications were determined through the analysis of data obtained from initial surveys conducted on the ICPs in which students were involved. Some classifications are supported by existing research about ICPs. To fully understand the scope of the attributes, descriptions are included that provide insight into the ways each attribute can appear in different ICPs.

TABLE I
ICP ATTRIBUTES AND THEIR DESCRIPTIONS

Attribute	Description
Duration	ICPs vary from single to multiple phases.
Scope	ICPs range from local to national levels.
Training	Training may or may not be provided.
Mentoring	Mentorship availability varies.
Team Forming	Assistance in team formation is variable.
Industry Involvement	Industry experience may be included.
Networking	Opportunities for networking may be offered.
Deliverable	Participants may produce ideas, prototypes, or plans.
Tech-Focused	Focus on technology is not emphasized.
Industry Type	ICPs may span various industry sectors.
Skills	Focus on technical, soft, or both skills.
Enrollment	Enrollment may be open or limited.
Multi-disciplinary	Teams may be required to be multi-disciplinary.
Prize	Prizes may be offered as motivation.
Workshops	Workshops may be provided for skill building.
Feedback	Provision of feedback is not consistent.
Test labs	Access to test labs varies.
Access to Capital	Financial support for projects may be available.
Intellectual Property	Intellectual property protection is not always offered.
Customer Discovery	Support for customer discovery may be provided.
Focus	Emphasis may be on profit, nonprofit, or sustainability.
Design Elements	Design elements may be a key evaluation factor.
Attraction	Recruitment methods vary from online to in-person.
Project-based	ICP structure may be project-oriented.
In Person	ICPs may be conducted in-person or remotely.

METHODOLOGY

I. Creation of interview questionnaire and student selection

This paper followed a qualitative research procedure in which data was collected through interviews and analyzed using an inductive thematic analysis. The extended research team, which comprised project consultants and research students, collaboratively crafted the interview questions. We sought to validate the interview questions by having a panel of students review them for their appropriateness. In addition, we conducted pilot interviews to evaluate the questions and the overall interview process. Questions expanded a variety of topics, including student experience, diversity, motivations for participating, skills learned, thinking creatively, and others.

Interviewees were recruited using a screener survey, which included demographic questions and brief Likert-like questions regarding their perceptions of ICPs. The survey link was sent to engineering and entrepreneurship students in three Northeastern universities. We invited interviewees from the list of respondents who participated in ICPs while ensuring that the sample included diverse interviewees and that different student groups were represented as much as possible.

II. Interviews

The team conducted interviews remotely over Zoom with 36 students, 50% being male and 50% being female. 36% of interviewees denoted that they were a part of an "Asian" ethnic group. 36% of interviewees indicated they were a part of the "White" ethnic group. 6% of students indicated they were part of both the "Asian" and "White" ethnic groups. The remaining interviewees were from other ethnic groups, including "Black" (6%), "Hispanic" (6%), and "Middle Eastern or North African" (2.5%). 7.5% of interviewees chose not to disclose their ethnic information. The majority (82%) of students interviewed were in one of the 4 years of receiving their undergraduate degree, either first-year students (12%), second-year students (34%), third-year students (24%), or fourth-year students (12%). The remaining 18% of interviewees had received either a Bachelor's, Master's, or Doctorate degree. The majors or areas of study represented by our interview pool varied, including Engineering & Sciences (66%), Hospitality Management (10%), Liberal Arts (7%), Arts and Architecture (3%), Agriculture (7%), and others (7%). In terms of student familiarity with ICPs in general, 26% of respondents reported being "Extremely familiar" or "Very familiar," 32% of respondents reported a moderate level of familiarity, and 42% of respondents reported being "Not familiar at all" or "Slightly familiar.

All interviewers received training on study objectives and interview skills. The interviews were conducted independently at predetermined times and lasted between 20 to 30 minutes. Prior to the interview, the team obtained informed consent from the interviewees and sought permission to record the sessions via video. The recorded interviews were then transcribed into text using an automated system and reviewed for accuracy. When necessary, the team cross-referenced the transcripts with the original video recordings to ensure precision. The interview transcripts were then organized by specific questions to upload into NVivo.

Questions touched on several areas, including ICP diversity, skills, experiences, challenges, networking, and others. The rest of the paper will focus on analyzing our interviewed students' responses to the following question: *What was your overall experience of the innovation competitions and programs (ICPs) you participated in*?

III. Analysis of Interviews

In the first stage of the analysis, three research team members systemically reviewed the transcript of each question and independently identified key concepts and codes relevant to the research question. In this stage, an inductive coding approach was used, that is, the team members independently extracted codes directly from the data without trying to fit them into pre-existing concepts or theories. This approach allowed for themes to emerge organically from the data itself. Next, the team members met to share and discuss the codes they generated independently and created a common set of codes for each question using a consensus-building approach. Then, the two team members independently coded the transcripts using the common codes agreed upon in the previous stage. These codes were combined to create the final codes. The Fleiss Kappa function in R, a programming language for statistical computing and data visualization, was used to calculate the inter-rating agreement among the independent coders. The resulting Kappa value of 0.539 (z=18, p=0.0) indicates that there was statistically significant moderate to high agreement among the raters. In the subsequent phase, two members of the research team analyzed the codes and transcripts. They used a consensus approach to group related codes into broader themes of concepts, as presented in Figures I and II.

IV. Findings

In this paper, we report the preliminary findings regarding students' overall ICP experience measured by the open-ended question: "What was your overall experience of the innovation competitions and programs you participated in?" At the highest level, students' overall experiences were grouped into two broad categories: negative and positive experiences. Figures I and II demonstrate the merger of lower-level codes into higher-level themes. In these figures, the thicker and darker the bars, the stronger the relations between the two boxes. The following section describes emerging themes, with quotes from interviewees as examples.

The "Challenges/Adaptation" theme includes students' negative experiences related to Covid-19 restrictions, disorganization, hard work, and large time commitment. Some excerpts from the interviewees are:

"... I think time commitment was pretty large, for at least what I was working on, for these kinds of engineering project teams ..."

"... There were definitely some late nights and a lot of hard work that went into it ..."

" ... But the project has been largely unmotivated and very disorganized among the other team members and our project mentor..."

Earlier papers [19, 20] identified time demand as a significant challenge for students. To make ICPs more accessible and appealing to all students, it is important to reduce the time demand. ICP organizers can achieve this by providing clear guidelines and expectations from the beginning. This will help to reduce uncertainty surrounding the time and effort required for these programs [21]. This can also reduce the unnecessary stress for students.

"Lack of diverse perspectives" was raised by a few students in this study.

" ... they felt that the information they're providing was like,…if you're white male, Sure, Absolutely, You're right. But if you're a black woman or any other ethnic group trying to go for a traditional small business loan? There's like a thousand requirements ..."

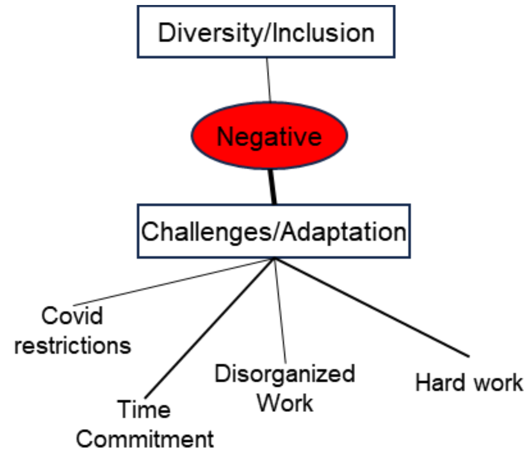

FIGURE I
STUDENTS' OVERALL NEGATIVE EXPERIENCES RELATED TO THEIR PARTICIPATION IN ICPS

The Personal Satisfaction theme captures the subjective feelings of fulfillment and achievement, such as "Making a real difference" and "Positive experience," as well as intrinsic values, such as "Fun experience" and "Great experience." We observed that a significant number of interviewees mentioned codes related to intrinsic values as many of the interviewees seemed to enjoy their experiences, such as:

"...Everyone was so friendly. It was the highlight of my junior year. I can't stop raving about it and I always tell people to participate and yeah, it was super fun ..."

"... So I think I had a really great experience. It was a great intro to everything related to my major ..."

The Practical Learning/Development theme includes a diverse set of codes indicating various aspects of practical and applied learning, such as "Advanced professional career" and "Gained technical skills." In addition, the interviewees emphasized that their learning experiences were applicable in real-world scenarios and provided new learning opportunities using codes such as "Translated into the real world" and "new learning experiences". A student response incorporating all these aspects was as follows:

"... Yeah, I think I gained a lot of good practical knowledge working with people, specifically that helped out in the other kind of job opportunities I've had so far. A lot of interesting technical knowledge that kinda overlaps itself with your other classes and causing you to be ahead in classes in some cases ..."

In this study, the participants emphasized the utility value of ICPs with the concepts included under the Practical Learning/Development theme. Note that almost every student identified Practical Learning/Development as part of their experience. In an earlier quantitative study [1], it was found that students valued technical and problem-solving skills the most among the learning outcomes of the ICPs. While having technical and problem-solving skills is crucial for engineering students, these skills alone are inadequate in preparing them to bring about change. Engineering students are expected to understand how their solutions add value and benefit those for whom they have been designed [1]. The current study identifies these skills as part of the Entrepreneurship Acumen theme.

Most interviewees mentioned collaboration and teamwork as a significant part of their overall experience, as indicated by the Networking/Teamwork theme. Several interviewees described a sense of community that has been fostered through collaborative efforts through challenging projects and collaborative problem-solving. For example, one interviewee mentioned,

"….within a semester, you're working on a project together. You're putting so much time and it's very good bonding system. So from a social perspective, it's been great to meet people that way. But also like, I've learned so much more than I would've ever thought ..."

By collaborating in teams and pursuing a shared goal, engineering students can enhance their sense of engineering identity and belonging. ICPs can facilitate this process. Interviewees also noted that ICPs provided them with an opportunity to develop leadership and organizational skills as a team lead. One interviewee stated,

" .. "I think like I said, the teamwork aspect was probably the most valuable, more so than the technical knowledge. Especially when I was one of the team leads dealing with organizing stuff for other people, considering I had no experience, so that was really helpful ..."

Based on these observations, we can argue that ICPs support student learning by providing experiential learning opportunities outside the traditional classroom setting that students consider mostly very positive experience. This learning is also well-rounded as practical learning in technical subject matters is complemented by development in professional and innovation skills, as shown in Figure II.

As seen in Figure III, the students' experiences in ICP were positive overall. The challenges were due to the heavy time demands and the need to manage messy and rigorous work. A few students felt that minority perspectives are not adequately considered in ICPs, which is a concern that ICP organizers need to consider carefully. Students highly valued the development of practical skills and ICPs contributing to professional growth. Teamwork emerged as essential, fostering community, enhancing learning, and developing leadership skills, underscoring the multifaceted benefits of ICPs.

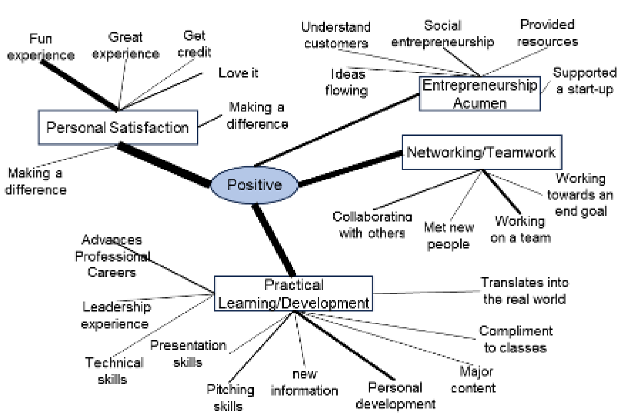

FIGURE II
STUDENTS' OVERALL POSITIVE EXPERIENCES RELATED TO THEIR PARTICIPATION IN ICPS

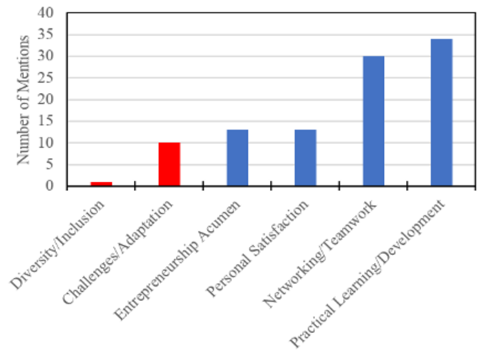

FIGURE III
FREQUENCY OF STUDENTS' POSITIVE AND NEGATIVE EXPERIENCES MENTIONED RELATED TO THEIR PARTICIPATION IN ICPS

CONCLUSIONS

Students who participate in ICPs generally have positive experiences, and these programs are perceived as offering significant benefits to those who engage in them. These experiences were split into the following themes: Personal Satisfaction, Practical Learning/Development, Networking/Teamwork, and Entrepreneurship Acumen. Competition organizers can better meet participants' needs by understanding student goals, takeaways, and perceptions of these themes. For example, students aligned with the Networking/Teamwork experience theme are more likely to benefit from and appreciate corporate sponsor events, networking, or working closely with their project team. Students looking for Personal Satisfaction experiences would appreciate embedded team-building activities, getting credit for their work, and engaging in impactful projects.

Taking this one step further and linking attributes directly to student experience offers even more personalization to enhance ICPs overall. For example, a student seeking Personal Satisfaction in their experience may cater towards in-person competitions that offer team-forming support and are of longer duration. However, a student more aligned with the Entrepreneurship Acumen theme would likely be most impacted by attributes like customer discovery workshops, access to capital, and test labs. The overall aim of ICPs is to improve the professional and technical skills of students across various majors. Considering the connections between the nature of these programs and students' experiences, memories, and aspirations during participation holds the potential to provide students with enduring, tangible, and meaningful experiences.

Examining the nuances of student experiences more closely and the most effective attributes to shape experiences by competition type remains on our future research agenda. There is much to be learned about how to best tailor the ICP structures to best support STEM student learning while considering their individual needs, concerns, and goals. When this gap is bridged, there is a large potential for ICPs to become a core part of the STEM student undergraduate experience, both in extracurriculars and embedded in their curriculum.

ACKNOWLEDGMENT

This material is based upon work partially supported by the Penn State Social Science Research Institute (SSRI) seed grant and the National Science Foundation (NSF) grant (DUE 2120936). Any opinions, findings, and conclusions expressed in this material are of the authors and do not necessarily reflect the views of the Penn State SSRI and NSF.

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