Paper ID #17903

The K-12 InVenture Challenge: Inspiring Future STEM Innovators

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The K-12 InVenture Challenge: Inspiring Future Innovators & Entrepreneurs

The K-12 InVenture Challenge inspires K-12 educators and students to innovate solutions to real-world problems of the students' choosing. Modeled after Georgia Tech's InVenture Prize, a 'Shark-Tank' style competition for Georgia Tech undergraduates that is televised throughout the state, the InVenture Challenge attempts to deliver the same authentic experience to K-12 schools by providing a framework, curriculum, and competition that can be used by K-12 teachers in a variety of disciplines to foster innovation and entrepreneurial thinking in student inventors. The InVenture Challenge is different from many other invention competitions in that teamwork is strongly encouraged and the teacher is a vital part of facilitating the process. When students participate in the InVenture Challenge, they do not work alone at home; rather, they are collaborating with up to two other student peers and their teacher is guiding them through an engineering design process. As a result, the InVenture Challenge is inclusive and diverse—about half of K-12 participants are female and nearly 40% are underrepresented minorities.

The contributions of this paper are two-fold. First, a model is provided for a K-12 innovation program housed at a university that is aimed at empowering underrepresented groups in STEM disciplines by looking further down the pipeline. Such a program could readily be replicated at other universities and is useful for broadening the perceptions around engineering and entrepreneurship, recruiting and retaining talent into STEM fields, and developing skills for innovation including communication and collaboration. The second contribution of this paper is an analysis of qualitative and quantitative data collected from InVenture Challenge teachers during the 2015-16 school year. Included in the research are surveys about self-efficacy for teaching both engineering and entrepreneurship as well as teachers' perceptions of their students' experiences with InVenture Challenge. Also included are interview and focus group data and thematic analysis about perceptions of student learning, specifics of implementation in different environments, and reflections on gender effects. In general, teachers perceive the InVenture Challenge as an engaging way of broadening participation in engineering, expanding the students' experiences outside of the classroom, fostering teamwork and collaboration, and building a partnership with Georgia Tech.

Introduction and Guiding Questions

Many studies have demonstrated the need for greater participation and increased diversity in science, technology, engineering, and mathematics (STEM) to sustain economic growth and meet global challenges[1]. One important element in the STEM enterprise is the process of creative innovation—of reimagining problems and solutions in new and different ways and designing and producing inventions that are novel, useful and of high quality. This endeavor requires people who have a broad set of skills, including technical knowledge, creativity, resilience, an understanding of the design process, entrepreneurial thinking, and strong communication skills[1].

Just as importantly, innovators need to be able to effectively collaborate and work in teams to solve problems—all talents grouped under the umbrella term "21st Century Skills" [2].

There are numerous reasons why proportional participation by all parts of the nation's workforce in creative innovation is important. Research has shown that diverse workforces outperform those with less gender and ethnic diversity, and that diverse design teams produce more radically innovative solutions[3, 4]. Currently, women and minorities patent inventions at disproportionately low levels, with women patenting at 40% the rate of men in the life sciences, and less than 10% the rate of men in IT fields[5, 6]. In 2012, Hunt et al. reported that only 5.5% of commercialized patent holders were women[7]. Most of the underrepresentation was attributed to women's underrepresentation in engineering and in jobs involving development and design.

The K-12 InVenture Challenge (IC) in conjunction with the Georgia Tech InVenture Prize for undergraduates comprise a K-16 pipeline for cultivating creative innovators. The programs blend invention and entrepreneurship to encourage students to find authentic and interesting problems to work on and develop viable, marketable solutions. To make these objectives accessible to K-12 audiences, the IC provides a structured, simplified approach for teachers to guide students through an open-ended design problem within a domain of the students' choosing.

In this paper, we will describe the K-12 InVenture Challenge and the K-16 ecosystem in which it is situated. Then, we will focus on research outcomes related to the following guiding questions: 1) To what extent does participation in the IC affect K-12 teachers' self-efficacy for teaching engineering and entrepreneurship content? 2) What are teachers' perceptions of the program's impact on students?

Background and Origins

The IC was originally developed as a high school-level competition with materials created by high school science teachers in partnership with the creators of the Georgia Tech (GT) InVenture Prize, an undergraduate invention competition with a live TV show airing on Georgia Public Broadcasting [8]. During the 2015-16 school year, 1500 K-12 students participated in the InVenture Challenge, with 60 of the top teams ranging from 1st through 12th grade presenting their inventions at the state finals. At the same time, the 2015 GT InVenture Prize attracted 500 undergraduate inventors with a live TV broadcast to 1500 studio audience members and 50,000 TV viewers, making it the largest collegiate invention competition in the US. Since piloting in 2012, K-12 InVenture Challenge participants have matriculated into GT and other universities, often pursuing entrepreneurial activities on campus. In fact, several InVenture Challenge participants, frequently girls and as young as 6th grade, are already pursuing patenting opportunities. The competition has continued to grow; the 2016-17 cohort has reached more than 2000 students in 15 counties with 80 teams planning to present their inventions at the state finals.

In the IC, students are free to work on a project of their choosing—there are no required themes or disciplines. We believe that keeping the projects in a currency of the students' choosing helps boost student engagement and willingness to see a difficult challenge through to completion[9]. Different teachers approach project selection or problem finding differently; this is an important skill for innovation and something that is unique to invention education as opposed to robotics and other STEM activities. Many students choose problems that are personal to them or their families, especially at the younger grade levels. Examples include ways to clean their pets' feet, ways to prevent their ice cream cone from dripping, and ways to help a baby wean from a pacifier. Some of the older students think more globally, such as new ways to filter water in developing countries or ways to prevent fertilizer from getting into runoff water.

The InVenture Ecosystem Model

One of the reasons that the IC has been successful and scalable at least thus far is the highly integrated ecosystem in which it is embedded. This ecosystem is shown in Figure 1, below.

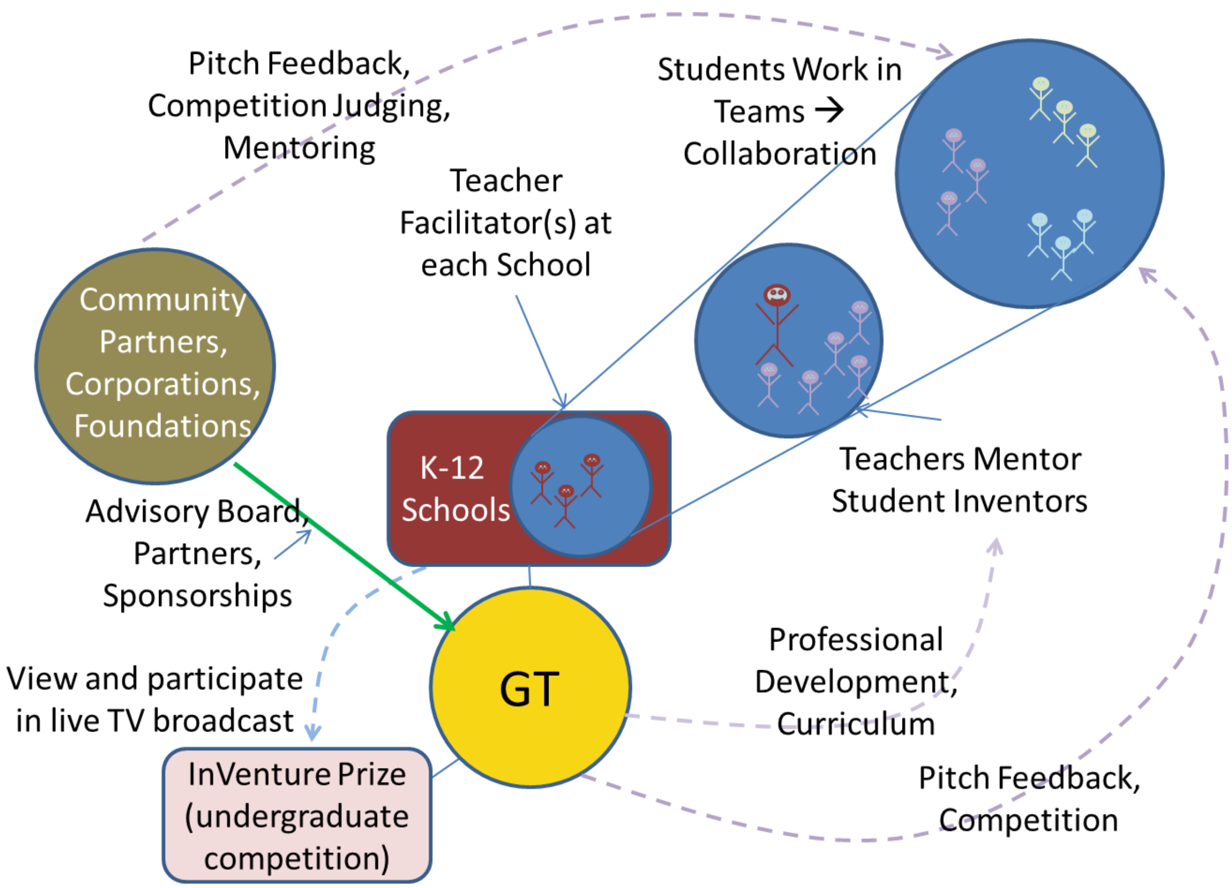

Figure 1: InVenture Ecosystem Model

Figure 1 depicts the core partnership between the university (yellow circle) and K-12 schools, with the blue circles each representing a different level of granularity within the K-12 schools.

The university partner plays critical roles throughout the invention process in terms of providing curriculum and professional development for teachers, as well as hosting the state finals, but also relies heavily on teacher facilitators, community partners, faculty mentors, and local school partners. For example, students are offered the opportunity to receive feedback on their ideas via virtual pitch practice held online. Both faculty members at the university and community partners can then serve as mentors and provide feedback on the pitches to help students prepare for their upcoming competitions. Previous research shows that teachers value the university connection and being able to take their students' ideas outside of the classroom[10].

Events, Offerings, and Professional Development

The IC offerings include teacher professional development workshops in the summer, virtual (online) interim pitch feedback for students in the winter, and the state finals competition in the spring. Schools often host local competitions to determine their top teams for state finals. At state finals, students come to campus to compete with their inventions and are judged by industry professionals, CEOs, government representatives, faculty members, and more. After their competition, they are invited to stay on campus for the live filming of the InVenture Prize, and sometimes K-12 students are featured in the broadcast. In addition, some schools come for additional field trips to see the Capstone Expo for senior design projects. For more details on the IC offerings, see Moore et al., 2017[10].

Methods

Research Design: This research utilizes a mixed methods approach employing both qualitative and quantitative sources (i.e., surveys, interviews, and a focus group) to determine the nature of teachers' experiences with InVenture Challenge and teachers' perceptions of the program's impact on students.

Participants: This study is being conducted with teachers who implemented the InVenture Challenge (IC) in their schools during the 2015-2016 academic year. All teachers were invited to take part in the study. A total of 38 and 23 teachers responded to the Fall 2015 and Spring 2016 survey, respectively. Half of the Fall, 2015 respondents are elementary school teachers (50.0%), and the remainder are evenly split between middle (21.1%) and high school (21.1%) grade levels, with a few in "other" types of schools (7.9%). Roughly half of the Spring, 2016 respondents are elementary school teachers (52.2%), and the remainder are fairly evenly split between middle (21.7%) and high school grade (26.1%) levels.

Data Sources:

<u>InVenture Challenge Teacher Survey</u>

This study employed an online survey, which was given once near the beginning of the 2015-2016 school year and again after the InVenture Challenge state finals in Spring, 2016. All teachers were invited to participate. Components of this survey relevant for the current work include demographics, information about teachers' backgrounds, and also several constructs: self-efficacy for teaching engineering, self-efficacy for teaching entrepreneurship, and teacher perceptions of the program's effects on students. Some of these constructs were assessed through validated instruments, while others were measured with internally developed items.

Teaching Engineering Self-Efficacy Scale

Self-efficacy for teaching engineering was measured with the Teaching Engineering Self-Efficacy Scale (TESS), which was developed and validated by Yoon Yoon et al., 2014[11]. These authors "define *teaching engineering self-efficacy* as a teacher's personal belief in his or her ability to positively affect students' learning of engineering" (p. 464). The scale assesses both overall self-efficacy for teaching engineering, and also the following four sub-constructs:

1) engineering pedagogical content knowledge self-efficacy: relates to their ability to teach engineering, based on their knowledge of engineering, in a manner that will facilitate student learning of engineering
2) engineering engagement self-efficacy: relates to their ability to engage students during engineering instruction
3) engineering disciplinary self-efficacy: relates to their ability to successfully manage a wide range of student behaviors during engineering instruction
4) engineering outcome expectancy: related to their belief in the linkage of their engineering instruction to student learning of engineering

The TESS includes items related to teachers' perceived ability with respect to planning, implementing, and managing the delivery of engineering content in the classroom. Prior research indicates that the scale and its subscales have strong internal consistency reliability, with researchers reporting Cronbach's $\alpha = 0.98$ on the overall measure and Cronbach's $\alpha = 0.84 – 0.94$ on the four subscales[11]. Responses were provided on a six-point Likert-type response scale ranging from Strongly Disagree to Strongly Agree.

Teaching Entrepreneurship Self-Efficacy Scale

The Teaching Entrepreneurship Self-Efficacy Scale is a locally modified version of the engineering instrument intended to measure teachers' perceived ability with respect to various aspects of teaching entrepreneurship.

Teacher perceptions of students' experience

A set of locally developed (not validated) survey items was included to assess teachers' perceptions of impacts of IC on their students' interests and abilities in engineering and entrepreneurship content areas as well as teamwork and communication. Specific student attributes include: enthusiasm for learning about engineering, enthusiasm for learning about entrepreneurship, presentation skills, teamwork, and understanding of a variety of engineering and entrepreneurship-related content topics. In the fall administration, the items asked about possible future effects of InVenture Challenge participation on students, while in the spring administration, the items were worded to ask about observed effects of InVenture Challenge participation on students.

Focus Group and Interview Protocols

The focus group guide and interview protocol were written by the research team, and were informed by previous research related to teachers' participation in IC. Focus group questions were designed to target new teachers' experiences with implementing the program and their perceptions of how participating in the program has impacted both their teaching and their students' learning. Focus group questions also addressed the level of school and administrative support teachers received, as well as any challenges they faced, during their first year of IC implementation.

The interview protocol questions were aimed at understanding why veteran teachers continued to participate, how IC fits with their pedagogical approach and regular course content, and how the program benefits their students as well as themselves. Four interviews were conducted, each lasting approximately one hour, with teachers who had participated in IC at least once prior to the 2015-16 school year. Both the focus group and the interviews took place during state finals in March of 2016.

Data Analysis: The method of data analysis chosen for this study is a qualitative approach of thematic analysis. Thematic analysis is the most used qualitative approach to analyzing interview and focus group data. According to Braun and Clarke (2006), thematic analysis is a method used for "identifying, analyzing, and reporting patterns (themes) within the data" (2006, p.79)[12].

Results & Discussion

InVenture Challenge Teacher Survey:

A total of 38 teachers responded to the survey in the Fall, 2015 survey administration, and a total of 23 responses were received in the Spring, 2016 survey administration. Some respondents were omitted if the data were mostly incomplete.

Teaching Engineering Self-Efficacy Scale & Teaching Entrepreneurship Self-Efficacy Scale

Overall results for both Teaching Engineering and Teaching Entrepreneurship Self-Efficacy are shown in Table 1. In general, mean responses on the both the engineering and entrepreneurship items were high across both survey administrations, with a majority of mean responses fall above a score of 5.0, indicating a mean response of "Agree" or higher. These results indicate a high level of confidence for various components involved in teaching engineering and entrepreneurship which remained mostly unaffected by participating in IC. Comparable mean levels of agreement were provided for the engineering and entrepreneurship items, suggesting that teachers in these two samples feel equally well-equipped to teach both engineering and entrepreneurship.

Table 1. Teaching Engineering and Entrepreneurship Self-Efficacy Results

Teaching Engineering Self-Efficacy Scale: Subscales	Fall 2015			Spring 2016		
	N	Mean	SD	N	Mean	SD
Engineering content knowledge SE (9 items)	37	5.03	0.65	23	5.25	0.67
Engagement SE (4 items)	37	5.53	0.52	23	5.63	0.46
Disciplinary SE (5 items)	36	5.26	0.72	23	5.29	0.65
Outcome Expectancy (5 items)	35	4.81	0.64	22	5.05	0.73
Teaching Entrepreneurship Self-Efficacy Scale	**Fall 2015**			**Spring 2016**		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**
I can discuss with my class how business and entrepreneurship affects my daily life.	37	5.24	0.72	22	5.41	0.67
I can help my students understand how different products appeal to different audiences.	37	5.38	0.64	22	5.59	0.50
I can spend the time necessary to plan entrepreneurship lessons for my class.	36	4.78	0.96	22	5.00	0.82
I can employ entrepreneurship activities in my classroom effectively.	35	4.89	0.90	22	5.23	0.87
I can craft good questions about entrepreneurship for my students.	36	5.11	0.82	22	5.32	0.78
I can discuss how design requirements for an engineering project relate to customer satisfaction and business success.	36	5.11	0.78	22	5.36	0.58
I am comfortable providing feedback about pricing and marketing aspects of student projects.	36	4.89	0.89	22	5.00	1.20
I can gauge student comprehension of the entrepreneurship concepts that I have taught.	35	5.17	0.75	22	5.32	0.78
I can assess my students' entrepreneurial thinking through activities, quizzes, class discussions, etc..	34	5.29	0.63	21	5.29	0.90
I feel it is valuable to teach entrepreneurial thinking to my students.	36	5.53	0.61	22	5.55	0.51

A common thread across both the engineering and entrepreneurship self-efficacy scale was the need for more time to plan lessons, as indicated by a generally lower mean response to that item as compared to others. These results echo those seen in our data from earlier surveys[10]. It is our hope that the InVenture Challenge curriculum materials will ease the burden on teachers, particularly returning teachers.

Some interesting patterns emerged from a comparison of mean scores on the four subscales described above: engineering pedagogical content self-efficacy, engineering engagement self-efficacy, engineering disciplinary self-efficacy, and engineering outcome expectancy. In both administrations, the lowest mean self-efficacy subscale score was provided for outcome expectancy, which is comprised of items related to taking direct responsibility for their students' achievements and improvements in engineering (e.g., "I am generally responsible for my students' achievements in engineering"). This echoes a finding from earlier work with this population[10], and could possibly relate to the notion that teachers serve more as a guide than a direct provider of information in the context of IC, and see the students' engineering-related achievements as the purview of the students themselves, rather than as a direct result of teacher action or effort. Further investigation of this finding should be undertaken in order to achieve a deeper and clearer understanding of it. In both administrations, the highest mean self-efficacy subscale score was provided for engagement, suggesting these teachers feel particularly well-equipped to engage their students during engineering instruction.

On the entrepreneurship scale, one item received relatively lower mean responses, (though still relatively high), as compared to other items: "I am comfortable providing feedback about pricing and marketing aspects of student projects." This is an area where the IC curriculum could be augmented to provide additional guidance to and resources for teachers on this topic.

Table 2. Teacher Perceptions of Students' Experiences

Teacher perceptions of students' experiences	Fall 2015			Spring 2016		
	N	Mean	SD	N	Mean	SD
Participating in InVenture Challenge will increase (*has increased*) my students' enthusiasm for learning about engineering.	37	5.65	0.48	22	5.50	0.67
Participating in InVenture Challenge will increase (*has increased*) my students' enthusiasm for learning about entrepreneurship/innovation.	37	5.65	0.48	22	5.41	0.67
Participating in InVenture Challenge will increase (*has increased*) my students' ability to clearly present their ideas to others.	37	5.70	0.46	22	5.55	0.67
Participating in InVenture Challenge will increase (*has increased*) my students' ability to work effectively in teams.	37	5.62	0.49	21	5.48	0.68
Participating in InVenture Challenge will increase (*has increased*) my students' knowledge of the engineering design process.	36	5.69	0.47	22	5.55	0.51
Participating in InVenture Challenge will increase (*has increased*) my students' knowledge of how products are made.	36	5.53	0.70	22	5.41	0.67
Participating in InVenture Challenge will increase (*has increased*) my students' knowledge of how to design an effective sales pitch.	36	5.69	0.47	22	5.59	0.50
Participating in InVenture Challenge will increase (*has increased*) my students' understanding of how to start a business.	36	5.33	0.76	22	5.05	0.95

Teacher perceptions of students' experiences

As shown in Table 2, across both survey administrations, all of the student work items had means of 5.0 or higher. These data suggest that teachers both expected and perceived a positive impact of IC on their students across a variety of outcomes. In both survey administrations, the same item received the lowest mean score: "Participating in IC will increase/has increased my students' understanding of how to start a business". This reinforces the need for supplemental materials specific to the business and entrepreneurial components of IC.

New Teacher Focus Group and Veteran Teacher Interviews:

Interview participants' (veteran teachers who had implemented IC at least once prior to 2015-2016 school year) background information is listed below to provide a better context for the qualitative data results:

- High School Teacher: AP Physics teacher, implemented IC as optional after-school program during 2015-2016 school year
- High School Teacher: AP Biology teacher, implemented IC with one AP Biology class during 2015-2016 school year
- Elementary School Teacher: implemented IC with elementary gifted program students during 2015-2016 school year
- Elementary School Teacher: implemented IC with elementary gifted program students during 2015-2016 school year

Focus Group Participants (all new to IC for 2015-2016 school year):

- Six teachers participated in the focus group
- Two teachers are at the elementary school level, three are at the middle school level, and one is at the high school level.

The following results are organized by emerging themes from the qualitative data. There are seven themes which emerged from the data.

Theme 1: Teacher Motivation to Participate in InVenture Challenge

Teachers discussed a variety of personal and professional factors that motivate their decisions to participate in InVenture Challenge. The "fit" of the IC curriculum with the teacher's preferred teaching style, and/or particular mission or focus of the teacher's school or program (i.e., gifted program, STEM agenda, engineering-focused school, AP science course content, etc.), was often cited as a motivating factor across the spectrum of interviewees and focus group participants. One interviewee who teaches AP biology mentioned alignment of IC with her district's push for increased STEM collaboration, and further discussed it as a good "fit" with her specific course as follows:

> *…within the context or within the standards for AP Biology, it's a lot of you need to be able to do research. You need to be able to come up with some type of solution for these issues. What's your opinion? What is your claim based on the evidence? So this was a part of their research, this is your claim, this is what you think the solution is based on what evidence. What research already exists out there that supports what you are saying so that went into the marketing research as well.*

The IC program as a good "fit" was highlighted by both elementary gifted teachers, who further commented that the program is well-aligned with the gifted program's standards around skills such as collaboration, communication, and divergent thinking. One counterpoint to this trend is that the other AP science teacher mentioned that a recent restructuring of the AP Physics course content and sequencing led him to change from implementing IC as a required in-class program, which he did in previous years, to a voluntary after-school program, which was the case for the 2015-2016 school year. He indicated that after the restructuring of the course, he did not have the time or flexibility in the curriculum that he felt is needed in order to implement IC as a required, in-class program.

Further, the elementary school teachers also discussed how they appreciate the opportunities the program offers, such as providing an integrated STEM experience and allowing students and teachers to move beyond the confines of their regular classroom and curriculum.

> *We are required to teach STEM, and so this would be the Cadillac of STEM, I think, because they go through so much research. They go through the math. The technology. Every part of it is science is all brought in together, so I feel like that they are using STEM every day.*

Focus group teachers also discussed their motivation for participating in the program. Mostly they were motivated by the inquiry approach inherent in IC, and gave examples of the ways in which IC allows them to go beyond traditional science fair-type activities. One teacher stated during the focus group discussion:

> *Science Olympiad is more, 'This is what you need to do.' The guidelines are there, and the expectations are there. I think the open-endedness for us was probably the best thing because our students don't seem to have the opportunity to have that experience very often. It did push them out of their comfort zone and make them really think about all the different ways.*

Other motivating factors discussed by the teachers included the IC association with Georgia Tech, the professional challenge of implementing IC, and benefits to students observed during the IC implementation.

> *I'm a gifted teacher and every part of the process really corresponds with our gifted standards, and the kids enjoyed it—they were very engaged in the collaboration and the innovation. It just was a really good fit…I think the biggest joy is seeing how the kids work together. They figure out their strengths, their weaknesses. They're investigating for the first time how to write a [survey] or how to use a CAD program and some of them are just a*

natural fit, intuitive with it. The ones that are really good at writing tend to stick to the writing requirements and then you have the kids who are really creative, out of the box, hands on kind of thinkers who like to do the tinkering with the prototypes. So, it's really cool to see them all come together.

Theme 2: InVenture Challenge Impact on Students

The teachers discussed their observation of the benefits of IC among their students as a result of their participation in InVenture Challenge. They have been organized into four subthemes, which are discussed below.

Subtheme 2a: Engineering and Entrepreneurship-related Factors

Teachers consistently discussed how they valued teaching engineering and entrepreneurship to their students, but their reasons for valuing this content differed. One high school teacher noted the importance of teaching students about understanding your customer and recognizing that business decisions entail constant risk analysis and cost-benefit tradeoff considerations; his reasoning behind the value of entrepreneurship education focused on specific, practical considerations within a business setting. An elementary school teacher noted that learning about entrepreneurship can prompt a variety of career interests, possibly ones that students had not previously considered; her value on entrepreneurship education relates to opening students' eyes to potential careers. This elementary school teacher also noted an increased interest in engineering, particularly among female students, as a result of IC participation.

I think an interest level. The girls, especially, who say, 'Wow, I didn't realize I could do this!'

The other elementary school teacher discussed entrepreneurship as it relates to students' abilities to turn their ideas into a real product, a level which some of her groups were able to approach. Some of these students expanded the scope of their project to include establishing contact with major companies. She also noted that IC emphasizes to students that successful designs must be rooted in consumer needs, and also highlights the importance of research and patent searches for students to determine the originality, or lack thereof, of their ideas.

This year we did a tiny bit better with this. I have one group, again, it goes back to the mentoring. The glasses group that I was talking about, they were able to go to a major movie chain in Atlanta that my brother-in-law works for and was able to talk to them about closed captioning glasses, but they may have an opportunity to pitch their idea to a Sony rep.

Focus group teachers also agreed that IC developed the *"entrepreneurship mind."* This included developing students' understanding of a real-world problem, creating a solution, and meeting with business partners to market a product. Further, teachers discussed how their students learned from the challenge of determining the marketability of the product. Students discovered the importance of market research and knowing the nature of the product components in order to decide the price for their product, so that they could make a profit. All of these are elements of entrepreneurship. Further, focus group teachers observed an increased interest in engineering, as well as an enhanced understanding about the breadth of engineering fields.

> *One of the best experiences for our students was interviewing. Surveying and interviewing people. They could see how a simple question about, "What do you think about my idea?" would lead to so many new ideas and, "Oh! I could do this..." To really listen to somebody else and hear what they're saying and add to your product because of a conversation you had.*

Subtheme 2b: Personal Growth/21st Century Skills

Both elementary school interviewees discussed IC participation as a source of confidence building for their students, specifically confidence related to how to research, how to improve something, presenting their work to an audience, and also self-confidence in terms of identifying their strengths. Elementary teachers also saw students improve their teamwork, innovation, and communication skills through IC participation.

> *I think self-confidence. I think they better understand…what they're really good at…you see some of your non-traditional kids shine in InVenture because of their creativity or quirkiness or they thought of something…They just leave with a good understanding of their own strengths and weaknesses and how to approach long term projects and deadlines in the future.*

> *…and the whole collaboration piece is huge. Because some groups, if they're not cohesive or if somebody's railroading the group, it dissolves pretty quickly so they learn how to deal with different personalities and learn how to work as a collaborative unit which I think is really important.*

High school level interviewees were less likely to bring up this type of student benefit, although one high school teacher highlighted the opportunity to present and improve presentation skills.

> *It's great exposure for the kids and I think that when ... I think the more venues that we can get these kids to present in and polish their product and their presentation, the better off the kids are going to be.*

Focus group teachers echoed the idea IC helps to build *self-esteem and self-confidence.* Students expressed that IC was *"the hardest thing"* that they had ever done. Specifically, teachers expressed that the "Pitch Day" activity, involving dry runs of their presentations, really built students' confidence and self-esteem. Focus group teachers also listed improved teamwork and communication skills as student benefits from IC.

> *These kids ... I saw a confidence level increase in their communication with their peers about their product. Some of my girls are really soft-spoken, but working with them about, "Oh,*

yes. This is the reason why," that confidence you could see become a real boost throughout this process.

Subtheme 2c: Understanding of Science

High school interviewees talked about IC as providing their students with a deeper understanding of and experience with the nature and process of science. They discussed IC's emphases on the role of iteration in the process of science, the need to confront adversity, the need for practice rather than memorization, and the importance of continuous improvement.

> *…kids will go…oh, I got an A in biology, because I memorized the book and took the test and I got an A. I tell them, physics isn't like that. You have to try and practice and see it this way, and it's an iterative thing, and this project, this kind of project, reinforces that kind of thing."*

> *They saw that too, like I should have changed this and I should have changed this, and they get to see what errors have occurred and what they should have changed. Oh, I need to redo my prototype, so they get to see all of that. Not just think, oh, if I do it one time it's going to be correct, and that's the end. I'm going to get it right the first time and that's it. No, that's not the case, and they saw that process, and I was so glad that they saw that process. I think that InVenture Challenge helped them to see that.*

One of the high school teachers ran her IC program with multidisciplinary teams of students from her AP Biology class and two other classes (engineering and technology), noting:

> *I like that fact that we were able to allow the students to work together so that they could see how this goes among various contents, not just this is strictly science, but you need the people in business and marketing, you need the people in engineering to help you…because they even think in school science is just science, math is math, and they think everything is separate, but we're trying to show them, everything is not separate. As a matter of fact, it's all interwoven.*

This notion was emphasized to a lesser extent among the elementary school interviewees, but one did value the lessons her students learned about failure through IC.

Subtheme 2d: Real-world Relevance

Interviewees at both grade levels emphasized that IC teaches students the real world application and relevance of topics they learn in school. Students' experiences in IC illustrated the essential nature of understanding various content areas in order to be able to accomplish their project-related goals. IC also provided students with insights into possible future career paths. One high school interviewee observed that students' work in IC illuminated the reasoning behind taking various courses: not just to graduate, but to allow them to pursue their goals.

> *I think it's a real world, real life, situation and we need to involve them in what's going on in the real world.*

> *Everything doesn't have to do with you have to go to college for 20 years to invent something, you can invent something here at this level. A lot of things are based on high school concepts… and I really break down some of the inventions, they're like, wow, this is a high school-, remember you made this in 10th grade physical science. Oh, my goodness, we did learn-. So it's a big eye opener, and they tie real life situations to what they're actually learning which makes it more relevant to them. I enjoy that part.*

> *What can you possibly do with this particular skill? Oh, well, I never thought about it like that. Maybe I can major in engineering, or maybe I can open up a small business to do this that and the other… So knowing that what type of classes will you have to take, don't you think you need to take business, as well, since you're learning this? They're like, oh, yeah, I guess I would need that class to see the relevance.*

Theme 3: InVenture Challenge Impact on Teachers

Teachers discussed various impacts of IC on themselves. One high school teacher discussed how IC provides a novel, real-world context to teach content in an authentic manner, and also exposes him to useful new content or presentation methods that he can incorporate into his teaching. He also reported enjoying "*living vicariously*" through his students as they worked through the IC. Additionally, one elementary teacher reported enjoying her role as a guide and a cheerleader for her students.

> *I love tinkering, and I love inventing, and even though I don't do it on a day to day job basis, I live somewhat vicariously through the kids doing that.*

A majority of focus group participants reported that the manner of implementing IC was consistent with their teaching styles. This was also mentioned as a motivating factor for participating in IC. As a result, they reported that it did not change their teaching style significantly. However, a high school engineering teacher discussed how the IC process is very different from what she usually does in her class.

> *I was challenged by it. I'm an engineer, so the open-endedness of it challenged my students and me sometimes because they want to know the answer. They want to know the end result. They want to know the specifics, and I'm like, "I don't know."*

Theme 4: School-level Support and Impact

Most interview and focus group teachers generally perceived that their schools and administrations were supportive of InVenture Challenge. One high school teacher acknowledged that due to the high time commitment that IC implementation entails for the teachers, the school administration would likely be unable to require participation.

> *but to ... for, say, an administration to say, well, you have to do that, that would be a hard thing to tell a teacher. It really is largely a voluntary thing, but still I get the sense it's admired and supported by the administration.*

The other high school interviewee discussed in detail the impact of IC, and in particular an IC Expo event she planned at her school. She discussed the fact that her school is disadvantaged and often viewed in a negative light, and that IC presentations by students served as a source of inspiration and pride not only for the participants themselves but also for the larger school community.

> *It's uplifting for them to see that even though you may be in this type of environment, it does not mean this is what you're limited to. That you can rise up to something else, something better. I liked that, you know, when I saw that on their face and they got to vote and they were so excited about it. The teachers, they were like oh, my goodness, the kids came back to the room and they were talking about this and said, why we can't do this, and why haven't we been doing this. So they were actually excited to know we have this capability. We just need the opportunity now…. It was exciting to see those students' expression. Then the other students are like oh, wow, look what we have done. I feel like I have accomplished something. The students at my school are proud of me because they didn't think, and now I'm a role model because they see that people at this school can do something outside of what is expected or what is being limited. It was, that was a wonderful day to see that.*

One of the focus group participant's role is as department chair in her school. She indicated that even though a lack of funding was a barrier to supporting the program, she encouraged all her teachers to participate because she really believes in the value of participating in such a program. During the focus group discussion, others mentioned that their principals are very involved and discuss IC very often in school meetings. Teachers also received support from the technology teachers, STEM coordinators, and other fellow teachers who could provide content support.

Theme 5: InVenture Challenge Learning Goals and Other Key Program Attributes

Interviewees were asked to provide their opinions on what IC's learning goals are, since it could be different for each of them. Teachers offered the following as components of IC's learning goals; the majority of these were cited by one or both interviewees at both grade levels:

- understanding and researching real-world situations
- problem finding and problem solving
- collaboration
- research and investigation skills
- creativity
- explore an idea that may not work
- try new things and expand students' horizons

These kids will be doing some kind of a project and they have to hook this wire up to that. Just the act of taking it ... heating it up and watching the metal melt and wow that connected. Simple little stuff like that that's like wow, I've never done something like that before. I take it too much for granted sometimes that they understand how these things work and that they've tried these things, so when they do a project like this, they're doing stuff that they've never been exposed to, and they're scared to touch. I might break something ...

Once again, it reinforces all of our standards of working with people that you're not comfortable with. Researching problems that people in the real world have, and how can we help solve those problems, so there would be the two main things I think of.

I would say first being a problem solver and knowing how to solve a problem, and then using the evaluative thinking process…and being able to use their creativity…and the whole collaboration piece is huge.

An interesting theme that emerged across both focus group and interview participants' discussions of IC was its open-ended, inquiry-based focus, which they often contrasted with something more task-based, such as a traditional science fair or Science Olympiad. The open-ended nature of IC was generally regarded as a positive attribute of the program, although some teachers discussed challenges inherent in this openness, such as a lack of experience and comfort with implementing this type of curriculum. Some students also struggled with the openness, although teachers generally found this to be a good experience for students, despite the fact that some students found it difficult.

InVenture lacks structure compared to science fair. The bad part about that is you're a little lost in the woods trying to find your way, but the good part about it is you get to be creative and inventive, and I like that aspect of it. I'm not complaining about the lack of structure, I kind of like it. But it does leave you a little cloudy at the outset sometimes. Mostly a good thing.

The ones that hated it absolutely despised the fact that they couldn't do this, this, and this and have it done. The ones that loved it loved it because they finally got to do something that was theirs. So for my kids, it was a love/hate. They either loved it, or they hated it, because of that open-endedness. They'd never been asked to do that before, which, over the next few years will change 'cause that's what we're moving toward with our STEM, but they hadn't had that.

It is a testament to the flexibility and customizability of the IC program and its curriculum that multiple teachers across grade levels, subject areas, and implementation settings reported that the IC was a good fit to the standards and content they needed to teach, and also to the general focus, approach, and/or setting of their school (e.g., district or school-level push for increased STEM instruction, gifted program, engineering-focused school, etc.).

Program components which entail visiting GT and/or interactions with GT faculty or other professionals were highly valued by teachers.

> *The fact that we have Georgia Tech mentor it, like for Pitch Day, that that's given to us, that's a huge advantage of InVenture…the kids get to see how things work at the college level and just that discussion with the professors on Pitch Day is just really golden. To see these professors really listen to the kids, really take their ideas seriously and the kids felt empowered by that and I don't think they get that experience with other curriculum, the pieces that we have.*

> *I really think having the students to come to [Georgia Tech's] Capstone was a big eye opener for them.*

Theme 6: Challenges Associated with InVenture Challenge Implementation

Teachers reported a series of challenges that they confronted during their IC implementations; most of this data comes from focus groups, as an explicit question on challenges was included in the focus group guide but not in the interview protocol. However, some interviewees discussed challenges in the context of other interview content. Some reported challenges related to limited resources in the form of money, time, and access to the computer lab for research. Others discussed challenges resulting from their lack of requisite content knowledge to assist students with their projects; some teachers turned this challenge into an opportunity to involve teachers from other disciplines to create a science community. One high school teacher intentionally instituted this "science community" approach by forming interdisciplinary teams, comprised of students from AP biology, engineering, and technology classes, to work on IC projects. Teachers also had some challenges related to clarity of requirements for various components of IC.

> *Just seeing them work together to work as a science community, in a sense, because that's something that I try to foster within all of my science classes. That you need people outside of just science. You need these other people, and this is how the world works. They're not just in one category, the entire building or the entire company is not made up of just one group of people, but different people with different jobs to work together to make the company run. That's what we were mostly trying to show the students that, you know, because they even think in school science is just science, math is math, and they think everything is separate, but we're trying to show them, everything is not separate. As a matter of fact, it's all interwoven.*

Theme 7: Impact on student subgroups

Veteran teachers were asked a question about whether they had observed any differential impact of IC participation on subgroups of students, either on the basis of gender, interests, ability level, economic background, etc. The teachers provided quite varied responses to this item. One high school teacher discussed ability level and "drive" for participating in IC, saying that students with lower ability and drive tended to group together, and that the presence of lower ability and drive students within a group tended to have a detrimental effect on that group's level of success in IC. The other high school teacher offered an interesting perspective on gender differences in the impact of IC participation, noting that in general he has observed that girls tend to view the world as a more complex place more so than do boys, and that IC projects tend to celebrate and benefit from this complexity, and offer a setting where girls can learn to successfully confront and manage the complexity without it leading to a bad grade. He also noted that IC has the potential to make a larger impact on a student from a disadvantaged background who has possibly had less prior exposure to these types of experiences, opportunities, and role models. The elementary school teachers did not report having observed differential impact for student subgroups.

> *Number 1, to get girls maybe to realize that all these loose ends are manageable, you just work on them and tie them up and continuously improve to make it better…for a girl that already sees the world as a complex place and they're dealing with these complexities and whatever this product and these ideas are is a good thing.*

Conclusions

The InVenture Challenge is a university-based K-12 outreach program that seeks to inspire students to see themselves as part of the STEM and entrepreneurial enterprise by instilling the tools and processes for innovation. The structure of the IC is flexible to allow individualized implementation and ownership in each school and district while being part of a supportive ecosystem with the university at its center. The model is a unique K-16 approach to fostering innovation and broadening participation in engineering. Data from participating teachers indicates that the program is eliciting many of the intended student outcomes including problem solving, collaboration, interest in STEM, entrepreneurial thinking, learning from failure, and creativity.

Future Work

The authors are currently in the process of collecting data from select student samples directly to further verify the student outcomes described by the teachers. In addition, we are beginning to plan for recruiting of more disadvantaged groups into IC, including small town and rural communities, and investigating the necessary community infrastructure and implementation models that make invention education possible in geographic areas that are not proximal to an urban or education hub.

Acknowledgements

We would like to acknowledge National Science Foundation Grant No. 1238089 for supporting this work. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We would like to acknowledge Dr. Marion Usselman for her continued input and mentorship, as well as Christopher Cappelli for his help in administering the focus groups. Finally, we would like to acknowledge the amazing teachers who participated in InVenture Challenge as well as the interviews, surveys, and focus groups. None of this would be possible without your energy, passion, and commitment to your students' success.

References

1. *The Engineer of 2020: Visions of Engineering in the New Century*. 2004: The National Academies Press.
2. P21 Framework Definitions, www.p21.org/storage/documents/P21_Framework_Definitions.pdf, Accessed September 11, 2013.
3. Díaz-García, C., A. González-Moreno, and F.J. Sáez-Martínez, Gender diversity within R&D teams: Its impact on radicalness of innovation. *Innovation: Management, Policy & Practice*, 2013. **15**(2): pp. 149-160.
4. Why Diversity Matters, http://www.mckinsey.com/business-functions/organization/our-insights/why-diversity-matters, Accessed April 7, 2016.
5. Ashcraft, C. and A. Breitzman, Who Invents IT? *An analysis of Women's participation in information technology patenting. Retrieved October*, 2007. **6**: pp. 2007.
6. Ding, W.W., F. Murray, and T.E. Stuart, Gender differences in patenting in the academic life sciences. *Science*, 2006. **313**(5787): pp. 665-667.
7. Hunt, J., J.-P. Garant, H. Herman, and D.J. Munroe, Why are women underrepresented amongst patentees? *Research Policy*, 2013. **42**(4): pp. 831-843.
8. The InVenture Prize,, https://inventureprize.gatech.edu/, Accessed September 28, 2015.
9. Ryan, R.M. and E.L. Deci, Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary educational psychology*, 2000. **25**(1): pp. 54-67.
10. Moore, R.A., S.H. Newton, and A. Baskett, The InVenture Challenge: Inspiring STEM Learning through Invention and Entrepreneurship. *International Journal of Engineering Education*, 2017. **33**(1(B)): pp. 361-370.
11. Yoon Yoon, S., M.G. Evans, and J. Strobel, Validation of the Teaching Engineering Self-Efficacy Scale for K-12 Teachers: A Structural Equation Modeling Approach. *Journal of Engineering Education*, 2014. **103**(3): pp. 463-485.
12. Braun, V. and V. Clarke, Using thematic analysis in psychology. *Qualitative research in psychology*, 2006. **3**(2): pp. 77-101.