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Evaluating Manufacturing Workforce Development Initiatives in Georgia

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Abstract

The next generation of manufacturing depends on innovation. Recent discourse focuses on technology development and deployment in manufacturing, deemphasizing the importance of innovative labor strategies. However, technology implementation is intertwined with people and impacts the types of work people do and the skills necessary to be successful. Contrary to popular fears, the jobs challenge is not that automation will replace the labor force, but that it will be necessary in order to fill the gaps left by the lack of qualified workers. By conducting an extended case study of three existing programs in Georgia, geared towards equipping students with 21st century and technical skills for manufacturing, our work highlights the need for institutionalized support across academia, industry, and government to aid in closing the skills gap. These innovative programs provide ideas for how to sustain and scale these and similar initiatives to deliver the necessary workforce development for manufacturers.

Keywords: Manufacturing; Workforce Development; Future of Work;

1. Introduction

Manufacturing is the backbone of the United States economy. Each day 12.75 million people in the U.S. go to work in manufacturing, a number that is expected to increase by 3.2 Million by 2025 [20]. The US manufacturing sector is ranked, by itself, the 9th largest economy in the world [29]. On a national scale, manufacturing accounts for 11.6% of U.S. Gross Domestic Product (GDP), one in seven private sector jobs, and the highest multiplier of any economic sector—every $1.00 spent in manufacturing adds another $1.89 to the economy [29].

Recently, discourse in the manufacturing industry has revolved around two critical topics: the digital revolution and workforce development. Global competition is driving companies to continuously improve their operations by maximizing efficiency and productivity. Emerging trends surrounding the digital revolution support the implementation of smart technologies in manufacturing environments to achieve these goals. This recent category of computing includes connected devices that make up the Internet of Things (IoT), as well as purpose-built sensor platforms, data capture, and analytic capabilities. The increased access and affordability of smart technologies is making deep inroads into how complex products are both designed and manufactured. While the potential benefits of such technologies are clear, there are also fears among many that technology and automation will ultimately replace human labor.

The success of efforts to augment human labor with automation and supporting technologies is seen as an immediate answer to the problems of an aging workforce and growing skills gap that leaves manufacturing jobs unfilled. Osborne and Frey expect that approximately 47% of the total U.S. employment will be automated over the next two decades [6]. Contrary to their findings the World Economic Forum predicts in “The Future of Jobs Report 2018,” that by the year 2022 about 75 million jobs may be displaced but that 133 million new jobs may emerge [15]. Deloitte and the Manufacturing Institute support these claims predicting that by year 2025 there will be 3.2 million jobs needed in manufacturing, of which 2 million will be left unfilled due to a growing skills gap [20]. Contrary to popular fears, the jobs challenge is not that automation will replace the labor force, rather it might be necessary to fill the gaps left by the lack of qualified workers.

These newly emerging manufacturing jobs demand different skill sets from employees. Manufacturers have indicated that the most serious skill deficiencies, in addition to technical skills, are the lack of "soft skills", often referred to as "21st Century skills", such as advanced problem-solving and critical thinking [20]. An Adecco survey of senior executives confirmed this finding - 44% of respondents reported deficiencies in soft skills such as critical thinking, communication, creativity, and collaboration, and 30% indicated that the skills gap most affects the manufacturing industry [28]. At the same time, the American public's perception of manufacturing jobs remains poor. A 2017 study by Deloitte and the Manufacturing Institute showed that 80% of Americans surveyed view manufacturing as an industry that is vital for economic prosperity [12]. However, only 50% of those surveyed believe that manufacturing jobs are interesting and rewarding, cleaner and safer, and more stable than manufacturing jobs of the past, and only 30% of those surveyed would encourage their children to pursue a career in manufacturing [12].

To address these challenges manufacturing workforce development approaches must evolve. More than 6 in 10 of the survey respondents in the Deloitte and Manufacturing Institute study indicated that programs that emphasize skills development through hands-on, industry-relevant activities would have the most success in generating awareness and interest in manufacturing [12]. To create such programs, involvement from industry, academia, and government is needed to develop industry-relevant curricula, encourage community participation, and garner financial support.

Our work presents an extended case study of three innovative, hands-on workforce development programs in Georgia that have been designed to raise awareness, improve perceptions of manufacturing careers and help students develop 21st century skills. We characterize the results of each program and identify opportunities and challenges facing their implementation. In doing so we provide ideas for how to sustain and scale these and similar innovative workforce development initiatives that will be necessary to meet the needs of the next generation workforce and close the skills gap in manufacturing.

2. Related Work

To better understand the need for new approaches to workforce development, there are two primary areas to consider. First, drawing upon earlier work in organizational studies [13, 22], new technology adoption and usage plays a crucial role in shaping workplace practices, thereby creating new types of jobs and required skill sets. Second, although the required skills are driven by needs in industry, the primary acquisition of these skills must occur within the education system. As a result, combined efforts of academia, industry, and government are necessary to successfully address workforce needs. Putting these topics in conversation provides a way to explore innovative solutions for creating the next generation workforce in manufacturing.

2.1. The Changing Face of Manufacturing

The focus of workforce development has historically been centered around training to produce more and better-prepared workers. The Workforce Investment Act of 1998 aimed to redesign the nation's workforce to better suit the needs of employers through qualified training programs and increased access to employment information resources [31]. This traditional understanding was temporal in nature and placed emphasis on information access while disregarding the role of skills-based education. Recently, thought-leaders have pushed for a more expansive view, defining workforce development as an interconnected set of solutions to meet employment needs that prepare workers with necessary skills, emphasizing the value of workplace learning, and considering skill demands of employers from the outset of education [17]. This perspective allows for flexibility in defining unique skill sets for each industry and prioritizes a symbiotic relationship between education and industry. However, this approach necessitates constant reevaluation, especially in a rapidly changing technology-driven era.

The complexities of workforce development are deeply intertwined with technology's influence on the changing nature of work. Disciplines such as Human Computer Interaction and Organizational Studies have shown that technology impacts workplace practices and causes shifts in the structure of the organization [22]. The integration of early forms of technology, such as email, into organizations impacted decision making practices and upset power dynamics [16]. Jobs were lost, and skill requirements changed for an entire generation of people entering the workforce. The ability to communicate instantly led to expectations for immediate response that have tethered us to electronic devices expanding far beyond the workplace setting. While these changes initially had the largest effect in office settings, we are beginning to see how new domains such as manufacturing are being transformed as computing continues to get smaller, cheaper, more connected. Technology is becoming ubiquitous throughout the whole organization, including the shop floor.

Emerging trends surrounding smart technologies encourage the implementation of new types of connected computing devices in the workplace. There are several examples of how these smart technologies are transforming working environments. The emergence of smart agriculture is creating networked sensors to monitor farm land and control irrigation systems [2]. The implementation of IoT systems in healthcare has enabled mobile devices to monitor and track cardiac rhythm from a patient's home [23]. Wearables, including smartwatches and smart glasses create connected employees on the manufacturing floor [1], and also enable connected soldiers on the battlefield [32]. The dominant narrative surrounding the implementation of these smart technologies emphasizes their ability to create organizational efficiency through real time data collection and predictive analysis. These technologies aim to solve problems, of an increasing population, addressing concerns of an aging workforce and growing skills gap, and improving the safety by developing and deploying smart technologies. The rapid expansion and acceptance of smart technologies within multiple industries, including manufacturing, accentuates the need to continuously evaluate and communicate workforce development strategies to understand how the required skills can be incorporated into education and training. It is critical that we comprehend how these new types of digital technologies stand to change the kinds of work people do, to educate the next-generation workforce and put people to work with technology instead of displacing them by technology.

2.2. Shaping the Future Workforce

For workforce development, the digital revolution means new skill sets are required to meet employers' increasing demand for productivity in the information age. Such skills are commonly referred to as "21st century skills," or "soft skills." According to the Partnership for 21st Century Learning, there are three categories that comprise this skill set: learning, literacy and life [34]. Learning skills include critical thinking, creative thinking, collaborating, and communicating. Literacy skills focus on the ability to accurately read and interpret information, media, and technology details [34]. Life skills promote flexibility, productivity, and leadership to create thoughtful, well-rounded, confident individuals and team players by focusing on social development [34]. However, overall lack of awareness about the types of jobs in manufacturing and the skills required to be competitive on the employment market contribute to workforce shortages and a growing skills gap. While the Deloitte and Manufacturing Institute study indicated that 88% of Americans believe that future manufacturing jobs will demand higher-level technical skill sets, 21st century skills were not even mentioned in the survey results [12]. The mismatch between existing labor and industry needs is due, in part, to rapid technology change and the resulting education and training lag. To fulfill future workforce needs and address current demands for the manufacturing workforce, education and training must occur in tandem. Both require an in-depth understanding of industry needs and forethought about technology integration.

A major component of communicating the critical skills gaps and implementing new workforce development strategies for reskilling existing employees and future workers in the talent pipeline requires partnerships between industry, academia, and government. At the University of Puerto Rico-Mayaguez, professors assessed the effectiveness of an experimental short course taught to students that specifically addressed needs in Puerto Rico's power industry [19]. The short, two-day educational course included hands-on activities that provided students with the opportunity to handle the necessary data and formulae required to solve the problems at hand and a deep examination into specific issues facing the power industry [19]. Students finished the course with an in-person tour of the power plant. The key components that led to the course's success were (a) the involvement of an industry practitioner on the teaching staff, (b) constant interaction with participants in order to analyze their questions and doubts, and (c) the inclusion of specific industry needs, in this case, proposed use renewable energy in Puerto Rico [19]. Without the active presence of industry, the project would have only a theoretical basis and lack tangibility. In addition, the plant tour and real-world problems presented provided authentic exposure to the power industry, its potential careers, and the skills that would be needed to work in Puerto Rico's energy sector.

Similar studies reiterate the importance of students applying learned and developing skills in real-world contexts, which leads to better conceptualization, analysis, and complex problem solving. Research conducted at Purdue Polytechnic Institute highlighted the importance of authenticity in programs that intend to close the skills gap [30]. In this case, authenticity was derived from academia partnering with local industry to generate real-world problems to be solved in coursework. Purdue developed a regional, industry-driven project design course that emphasized student involvement in current and pressing issues in manufacturing. The study found that educators can work with regional industry to successfully help them cultivate talent so long as the skills learned can be directly applied to the local manufacturing ecosystem, and thus create a natural connection between local industries and potential future employees [30]. Students were able to develop skills that were directly applicable to their future careers. These results highlight the significance of industry engagement with academia and provide a concrete example of how local industry can get involved.

One of the drawbacks of these programs is their time-related nature which limits broad scale impact. Collegiate level programs are often bound to an academic schedule which entails a substantial commitment. Often long-term industry partnerships only occur with large corporations who have the financial means to sustain such efforts. Additionally, research shows the importance of exposing students to science, technology, engineering, and math (STEM) related careers much earlier in their education rather than waiting until college [5]. The Vertical Educational Enhancement model, developed to enhance STEM education in a dynamic global and industrial environment, argues that interaction with primary levels of education are crucial in developing well-prepared students into university level training programs [5]. Integration of career-focused and industry-driven curricula into primary and higher levels of education both increases interest in the field of manufacturing and produces a better prepared workforce.

Both through support of university-based courses, such as the programs mentioned above, and through grants, the government is placing emphasis on its role in closing the skills gap. The NSF Future of Work initiative at the Human Technology Frontier was launched in recognition of "the changing ways we produce goods, provide services, and collaborate with our colleagues" [33]. The focus draws attention to "a changing future work force, making education and lifelong learning important priorities" [33]. Recent STEM related grants have emphasized a focus on industry-focused education and closing the skills gap. For example, the Technical Career Pathways for Rural Manufacturing project, funded by the Division of Undergraduate Education aims to develop a program that raises awareness of technical skills related to manufacturing and prepares students for both higher education and a career in industry [27]. The project does so by offering online courses in employability skills, delivering summer skills academies in machining, recruiting students from rural areas, and providing counselling and mentorship. Additionally, the Division of Undergraduate Education funds the Necessary Skills Now project, which fosters collaboration between state-level educational entities and employers across America [3]. The goal of the project is to develop, pilot, and revise instructional materials that integrate sector-specific and employability skills into coursework [3]. Workforce development relies on having a solid grasp of the types of skills industry needs to create sustainable programs backed by government support.

3. Context and Research Methods

National trends are echoed in Georgia as manufacturers experience a shortage of workers with the skills needed to succeed in the modern advanced manufacturing workplace. Manufacturing in Georgia is one of the state's six strategic industries for economic development and accounts for 92.3% of exports and 11.1% of GDP [36]. Approximately 400,000 Georgians are employed in the manufacturing sector which makes up 8.6% of total state-wide employment [36]. Ranked the number one private industry contributing to economic impact, at $61 billion annually, manufacturing is the backbone of Georgia's economy [36].

The Georgia Department of Economic Development is the state's lead agency for attracting new business investment, supporting the expansion of existing industry and small businesses, and aligning workforce education and training with in-demand jobs [9]. The Center of Innovation for Manufacturing (COIM) is a unique, state-funded resource within GDEcD that provides expertise, facilitates connections, and supports innovative programs that help existing Georgia manufacturers grow, prosper, and compete globally. The Center accomplishes its mission by assessing manufacturers' challenges and providing connections to the right resources in academia, industry, and government that enable manufacturers to develop solutions. In addition to working with individual companies, COIM works in partnership with manufacturers, academia, government, and other organizations to identify and support strategic programs that lead to the growth of Georgia's manufacturing industry as a whole.

The workforce development programs studied in this work have been supported by COIM through several mechanisms, including contributions to program design, leading or supporting event implementation, and/or providing seed funding. They provide a glance across the educational spectrum from elementary school to high school and college. Each program exemplifies a different level of engagement, ranging from a one-day commitment to a multi-year involvement. The distinction between these programs and existing efforts is based on the unique positioning of COIM in the state. Through its interactions with manufacturers on a daily basis COIM is able understand the workforce development needs of manufacturers in Georgia. As a state agency whose mission is to support the manufacturing sector COIM is also able to transcend the traditional boundaries of academia, industry and government to form and support meaningful partnerships that solve challenging problems faced by the industry as a whole, such as the need for innovative workforce development programs. The example programs presented in this work are not meant to be prescriptive rather the goal of this paper is to add to the conversation surrounding the future of work in manufacturing, share the knowledge gained through program implementation, and offer possible solutions to workforce development initiatives that will help to close the skills gap and create the next generation manufacturing workforce.

3.1. Program Descriptions

3.1.1. *K-12 InVenture Prize and Accelerator Program*

The K-12 InVenture Prize is modelled after the Georgia Institute of Technology (GT) InVenture Prize competition, the nation's largest undergraduate invention competition. The goal of the InVenture Prize is to encourage students to identify and create solutions to real-world problems by combining analysis and creativity [11]. The competition champions 21st century skills and acts as a mechanism for introducing these new types of skills into the classroom. The K-12 program provides teachers with free online curriculum that is based on the principles of design thinking. Each teacher and school can modify the program and it can be incorporated into classroom curriculum or offered as an afterschool activity. Participating schools select the top teams to participate in the state level competition hosted at Georgia Tech each Spring semester. The winners represent Georgia on a national stage as part of the National Invention Convention and Entrepreneurship Expo [10]. The program has experienced tremendous growth across the state, as the demand for hands-on education and applied learning is being promoted. Recently, the success of both of the college and primary level InVenture programs was recognized at by the state of Georgia, which has led to the creation of the Georgia InVenture Prize. This initiative is led by the Georgia Chamber of Commerce along with partners including the University System of Georgia, the Technical College System of Georgia, private colleges and Georgia Tech [8].

To continue to grow the pipeline of students participating in the K-12 InVenture Prize and increase exposure to entrepreneurship and product development, an extension program was developed called the K-12 InVenture Summer Accelerator. COIM's involvement in judging and sponsorship in the K-12 InVenture Prize sparked a partnership between COIM and the Georgia Tech Center for Education Integrating Science, Mathematics and Computation (CEISMC), which then led to the creation of the Summer Accelerator program. COIM's goal in supporting the program was to introduce students at a young age to manufacturing concepts and help them develop 21st century skills by having them experience the product development process. The summer accelerator is a weeklong "summer camp" run through Georgia Tech CIESMC. Registration is open to students across the United States and takes place at Georgia Tech for a fee of approximately $400 per student. The funds are used to cover the costs of instructors and materials. The event builds skills that are not typically taught in traditional educational environments, such as design and prototyping. The target audience of the program is middle school students, which is the largest population participating in the K-12 InVenture Prize. A key goal of the camp is to get students, from a young age, thinking about entrepreneurship, innovation, and different education and career paths. Another goal is to have students experience how important manufacturing is to each of these topics.

The week-long summer program takes middle schoolers from customer discovery through prototyping, culminating in a pitch presentation to judges and parents. The first day begins by delving into problem identification and brainstorming. Students are asked to situate themselves in a problem space by identifying a topic that they care about, a repetitive task or a problem they have encountered in their own lives. They are told that they will choose one of these problems to solve during the week. Hands-on activities and games are used to explore ideas and skills. The afternoon session shifts to explore different types of intellectual property (IP) and patents by featuring a guest IP lawyer. The second day builds on the selected problem area by focusing on ideation and design for possible solutions. Students can form groups or choose to advance their own idea for the remainder of the program. The afternoon features a successful inventor who shares their personal journey through the design process. Day three is action packed, discussing both market research and manufacturing. Students are asked to conduct market research in the classroom by creating surveys for their parents, teachers and peers to complete. The process highlights the importance of identifying users and market potential. With a well-crafted solution, the afternoon transitions to manufacturability. The emphasis is placed on answering questions such as: How are you going to make your product? How much is it going to cost? How much are people willing to pay? What materials do you need? This acts as a segue for students to begin physically prototyping their ideas. The entirety of day 4 is spent designing and building physical prototypes. Students are given an intro lesson to TinkerCAD and have access to 3D printers as well as a myriad of other materials including cardboard, fabric, and wood. The program culminates on the 5th day with an overview of business planning, discussing topics such as funding and marketing, in preparation for afternoon pitch presentations to parents and judges. Students who attend the summer accelerator are given the opportunity to partake in the state K-12 InVenture Prize, if their school does not already participate.

3.1.2. *Northwest Georgia National Manufacturing Day*

In celebration of National Manufacturing Day in October, COIM organizes an annual daylong event for early high school students to raise awareness about manufacturing and practice 21st century skills through hands-on activities. The event brings together local industry and government to expose students in Northwest Georgia to manufacturing and entrepreneurship. Each year an invitation is extended to approximately 9 high schools across two different counties in the Northwest Georgia region, bringing approximately 100 students and teachers together for a full day of learning. This synthesis of different schools creates a forum for collaboration and thought sharing about topics such as how to bring hands-on STEM activities and manufacturing topics into their classrooms. COIM has been hosting the event for three years. As the sponsor, COIM has both organized the event and covered all costs with the exception of food.

There have been two primary formats for the event. The first focused on showcasing college level start-up companies in Georgia. Manufacturing industry partners are spotlighted throughout the event as a way to become recognized by the students as a potential employer. Exposure to the start-up companies plants the seed for creating a new business and contributing to economic development in the State [24]. The kicked off with pitch presentations followed by small group breakout sessions. The start-up teams led student groups through brainstorming and ideation surrounding a real-world business problem that the company was experiencing. Breakout sessions occurred in private classrooms with randomly assigned groups comprised of 10 to 15 high school students. A primary challenge, however, was that this format relied heavily on garnering participation from several start-up companies, and on each start-up team being active and engaging at the event. As a result, the event was reorganized the following year to revolve around only one start-up company and provide students with a hands-on activity.

In 2017, the event featured a start-up company called Sumo Robot League from Augusta, Georgia. Sumo Robot League is managed in partnership with HACK Augusta, a non-profit operating out of the Clubhou.se maker space in downtown Augusta, GA [16]. The start-up company has developed simple, competitive robots that can be assembled and programmed in a relatively short period of time, and then immersed in a sumo wrestling style competition where the robots attempt to push one another out of a competition space. Sumo Robot League has also created a “scalable STEM education platform that offers an affordable competitive robotics curriculum for middle and high school students” [25]. During the NW GA Manufacturing day event, two students were provided one robot kit to assemble and code, over the course of a 4-hour session. A Sumo Robot trainer provided an introductory coding lesson during the first half of the day. Local industry and government partners played an active role in the session answering questions and even helping students with assembly. The ultimate challenge was to work towards a Sumo Robot competition. Each team was able to battle at least one other group during the program. At the conclusion of the event, each school represented was presented with two robots to take back and share with other students and teachers. Although observations showed that students were heavily engaged throughout the event, based on partner feedback from industry and government, the program for 2018 reverted to the initial start-up showcase format.

3.1.3. *TCSG-GTMI Internship Program*

Developing the talent ecosystem for manufacturers includes equipping students preparing to enter the workforce with practical hands on experience in combination with 21st Century Skills. In 2012, the Georgia Tech Manufacturing Institute (GTMI) and the Technical College System of Georgia (TCSG) formed a partnership to improve Georgia’s advanced manufacturing skills gap. A committee of faculty members from the TCSG and GTMI was formed, and the group held a series of meetings to brainstorm partnership programs that could address gaps in 21st Century skills, as well as technical skills in the areas of CNC machining, welding, mechatronics, additive manufacturing, and other technical disciplines. These are the skills consistently reported by Georgia manufacturers as critical to their ability to be competitive, yet often lacking in the pool of potential workers for skilled production and technician jobs [26]. The committee proposed the formation of a paid internship program in which students from West Georgia Technical College (WGTC) would work at GTMI on complex, real-world advanced manufacturing research and technology transfer projects. To initiate a pilot program, GTMI was awarded $20,000 from the Center of Innovation for Manufacturing in 2013 to cover student stipends and travel costs.

The two West Georgia Technical College interns that participated in the pilot program were paid an hourly rate competitive with what they would earn in industry, and worked approximately 20 hours per week, depending on their availability and GTMI project needs. Their work schedule was customized so that it did not interfere with their coursework at WGTC while still enabling GTMI to meet the demands of its internal (GT) and external (start-ups and industry) customers. Each intern worked under the guidance of a GTMI faculty or staff member on several projects that focused on developing prototypes for Georgia Tech start-up companies, and creating jigs, fixtures, and other equipment to support manufacturing-related research performed at Georgia Tech.

The students were involved in each step of the engineering design process, from the initial stage of meeting with the customer to understand needs and constraints, through ideation, conceptualization, design, manufacturing process selection and planning, machine programming, fabrication, and then final quality inspection with the customer at delivery. Participating in all of these steps allowed the technical college students to experience the engineering design process from start to finish. It also required them to apply critical 21st Century Learning skills, such as critical and creative thinking, collaboration, and communication; Literacy skills to accurately read and interpret information and technology details; and Life skills to be flexible and productive while working with a team of people possessing a broad range of backgrounds and skill sets. They also developed and fortified technical skills in Computer Aided Design (CAD), and Computer Aided Manufacturing (CAM), manual and CNC machining, additive manufacturing of plastics and metals, and mechanical and electronics assembly. Bi-weekly interviews were conducted with each participant to assess the student's progress, monitor program outcomes, and identify areas for program improvement

Based on the successful model developed in the pilot internship program, in 2016 GTMI was awarded $283,000 by the Workforce Division of the Georgia Department of Economic Development to expand the pilot program from two students in the prior two years to a full internship program with 20 participating students over the following three years. In the full internship program, students were paid a stipend of $6,000 for working 24 hours per week for a period of six months. In addition to being paid for their work, students were offered the opportunity to also apply for elective credit that counted toward their degree at their technical college. The full internship program also allowed participation from students at several technical colleges within a short drive (~45 minutes - 1 hour maximum) of Georgia Tech, in addition to West Georgia Technical College. The students were supervised and mentored by a full-time GTMI staff member with industry experience as a Machinist and Mechanical Designer, who led all GTMI fabrication projects. To increase the number of participating students from 2 in two years to 20 in three years, two technical college interns participated in the program in each 6-month program period. The program periods overlapped by approximately 1.5 months so that the current interns could help train incoming interns, thereby solidifying their knowledge gained in the program, and reducing the training burden of the GTMI Mentor. To monitor student progress, identify areas for program improvement, and encourage students to reflect on their experience, students were required to submit three interim progress reports and a final report that briefly described the projects that they worked on and what they had learned. The nature of the work was identical to the real-world project work performed during the pilot study, and the goals remained the same - to develop the 21st Century and technical skills that Georgia manufacturers need in their employees.

3.2. Data Analysis

Taking an active and ongoing role in each of these programs has provided the authors with first-hand knowledge and direct feedback from program participants. Through informal conversations, surveys, and planning and feedback sessions this work represents a compilation of perspectives about program results from academia, industry and government. A grounded approach was used to analyse feedback and observations through open coding to establish overarching themes [4]. Borrowing from Charmaz's version of grounded theory allowed for more flexibility to embrace the diversity of the programs and participant experience. This work reflects a snap shot in time amidst ongoing efforts to continue to revamp and grow innovative manufacturing workforce development programs in Georgia.

4. Program Outcomes and Barriers

Our findings begin to characterize the complexities of creating programs in that aim to prepare the next generation of workforce in manufacturing. Through open coding prominent barriers emerged surrounding ideas of growth, funding and differing priorities between industry and academia, when implementing programs designed to address the skills gap in the manufacturing workforce. These themes revealed the overarching importance of leveraging partnerships across all three entities - academia, industry and government - to sustain and scale workforce initiatives. This section discusses these themes in each of the programs and points toward common needs of program initiatives that suggest opportunities for successful interventions.

4.1. K-12 InVenture Prize and Summer Accelerator

Studies of childhood education continue to prove the importance of early STEM educational experiences beginning at infancy [14]. Introducing STEM practices at very early stages of education and development increases the likelihood of career and behavioural success in adulthood [21]. The K-12 InVenture Prize and summer accelerator program target this early age demographic.

The summer accelerator acts as a feeder program for the K-12 InVenture Prize creating a pipeline of students who are prepared to take their ideas to the next level. The summer program was first offered in 2017 with a total of 20 students enrolled. In 2018, the program expanded to offer two separate one-week sessions during the summer. In total, 33 students were enrolled across both week-long sessions.

During both years, the success of the program in preparation and delivery relied heavily on the teaching staff. The amount of material covered in one week requires a significant amount of upfront planning. Experienced primary level teachers were hired to craft the weeklong program curriculum and host the camp. Feedback from students during the first year led to changing the curriculum to include more time with hands on building and prototyping during the second year. Additionally, students were encouraged to use more traditional materials such as construction paper and wood, as opposed to 3D printing, due to time constraints. The teachers also perceived higher levels of engagement when students worked with more traditional, hands-on materials. Parents expressed sincere admiration for the summer program and have been impressed with student output each year. Particularly the business acumen acquired in such a short period of time including cost assessments and market evaluation. The student prototypes have been unique and wide-ranging, addressing large-scale problems, including water quality and school safety, or daily organizational challenges such as toy storage and access. Several summer program participants continued to ideate on their ideas and have gone on to compete at state and national levels.

The strengths of the K-12 InVenture Prize and Summer Accelerator programs are flexibility and scalability. Teachers expressed the value of being able to give students a well-scoped problem area or, for older students, an open slate, attributing to the application of the ideation process across all grade levels. Additionally, as exemplified by the summer program, the materials can operate successfully at both small and large scale. The summer program condenses the year long curriculum into a week long experience. Now that the curriculum is developed it is more easily transferable to other locations and instructors. The summer accelerator is open to anyone; however, participation may be limited because of financial means or physical access. During both years, students were commuting long distances and participants from out of state had to find their own forms of lodging drastically increasing the cost of participation. The program relies heavily on parents and teachers taking initiative and being aware of the opportunity. More importantly it is necessary to have school system support for long-term participation in the larger K-12 InVenture Prize program. One of the limiting factors for program expansion is continuing to incentivize teachers to instruct and creating mechanisms for increasing access.

4.2. Northwest Georgia National Manufacturing Day

The concept behind the Northwest Manufacturing Day event is to create an experiential learning opportunity for rural communities to change student perspectives about manufacturing careers. Dr. Britney Wilson of the participating Calhoun College and Career Academy shared that the event *"provide[s] our students with an engaging meaningful experience that exemplifies the creativity and innovation expected in the manufacturing industry. Our goal is to prepare all students with a skill set to meet the workforce needs of Northwest Georgia"* [24]. This recognizes the importance of working hand in hand with local industry to meet workforce needs which depends upon positive student exposure to manufacturing.

The success of changing the narratives surrounding manufacturing jobs relies heavily on strong industry involvement. COIM's focus on a student-based activity deemphasizes industry's role because manufacturers have expressed an unwillingness to participate stating that they are unable to halt operations or leave the factory floor. In 2016, the event hosted approximately 60 students not including teachers for the entrepreneurship showcase. Student engagement during the event was limited in direct association to the start-up team presentations as previously discussed. The event model shifted in 2017 to focus on Sumo Robot. Approximately 100 students participated, additionally, each school was asked to send at least 2 teachers to accompany students to help facilitate the activity. Most recently, in 2018, 78 students attended the event modeled after the original entrepreneurship showcase.

The reversion of the 2018 National Manufacturing Day event to the entrepreneurship model was based on partnership feedback. This feedback was revisited at the beginning of the planning session in July for the 2018 event. Industry and government partners continued to emphasize that the Sumo Robot event did not "engage" the students. This runs directly counter to the feedback from teachers, invited attendees and students during the 2017 event. Teachers expressed interest in having Sumo Robot come to their schools and do other events. The majority of feedback was that the event should have been longer. This was very valid because most groups had to trouble shoot their code or mechanical components. Reflecting on the outcomes of the event, COIM viewed this as true exposure to real-world problem solving. The side effect of having a longer event would be twofold. First, the time would extend outside of normal school hours including bus transportation and second, it increases the risk of students not being focused or losing interest overtime.

4.3. TCSG-GTMI Internship Program

In total, 2 students in the Engineering Technology program at West Georgia Technical College (WGTC) participated in the TCSG-GTMI Internship pilot program, and 4 students in the Precision Machining and Manufacturing program at WGTC participated in the full internship program. All participating students self-reported that they enjoyed the program, participated in a wide variety of challenging projects, gained a significant amount of new knowledge, and practiced a number of valuable skills during their internship. One called the program "*An opportunity of a lifetime*" while another said that

"*This has been an incredible opportunity that I can't imagine getting anywhere else*."

After completing the internship, one student in the pilot program was hired directly by GTMI to work on a part-time basis while finishing undergraduate studies in Engineering Technology at a nearby university. Two participants in the full internship program were hired by Georgia manufactures, the first as a CNC machine tool operator earning $22.50 per hour, and the second as a die maker earning $26 per hour, at the conclusion of their internships. One participant left the full internship program after approximately 1.5 months because the student received and accepted a strong job offer from a manufacturer. The final participant in the full internship program was hired into a family business in a field unrelated to the program.

In spite of the program's success in terms of student learning outcomes, and the benefit that GTMI received by having additional student support for its projects, several challenges were encountered. The full internship program concluded in 2018, after only 4 participants, due to new funding guidelines from the sponsor that required a significant reduction in the cost per participant. Significantly lowering the cost per participant would have required lowering the student stipend to an amount that would no longer be competitive with industry internship pay. Indeed, as described above, one of the four students enrolled in the full internship program left the program early to take a job in industry. This would have made finding students for the program more difficult or nearly impossible.

The recruiting process for the internship program relied heavily on the GTMI Mentor connecting directly with a faculty member in the Precision Machining and Manufacturing Program at WGTC. As the full internship offered the opportunity for students from other Georgia technical colleges to participate, a personal relationship with an instructor at each technical college was necessary to make this happen. When contacted by the GTMI team technical college instructors routinely showed a strong interest in supporting their students' participation in the program. However, likely due to demands on their own time to teach their classes and work with students in their programs, it was difficult to engage additional technical college faculty in the program to the point where they would recommend and encourage their students to apply and participate.

Another barrier was that there are only six technical colleges that are within a 45 - 60 minute drive of Georgia Tech that have programs in manufacturing subjects, namely Atlanta Technical College, Chattahoochee Technical College, Georgia Piedmont Technical College, Lanier Technical College, Southern Crescent Technical College, and West Georgia Technical College. The drive was a significant time commitment for students already participating in the program, and it would only expand for students enrolled in technical colleges further from Georgia Tech. Finally, the program was limited by the number of students that the program can support. With one full time staff member as the GTMI Mentor, given other job responsibilities it was not feasible to mentor more than two students at a time.

5. Discussion

Each of these programs should be considered an example of a successful and innovative workforce development program. Students and partners derived significant perceived and self-reported benefits as a result of their participation in these initiatives. Nevertheless, consistent areas of opportunity across the programs emerged that highlight systemic issues when developing workforce initiatives to address the skills gap. The challenge becomes how to create engagement opportunities in a way that continues to support and extend the ability for manufacturers to grow.

A recent study conducted by the National Center for Construction Education and Research (NCCER), a non-profit education foundation created in 1996, has already taken major strides towards action by collectively identifying areas of opportunity and the challenges therein. NCCER identified and defined seven policies for industry and government agencies to "restore the dignity of work" [35]. These seven policies were further categorized, the first three are short-term and remaining are long-term policies:

1. Establish and strengthen career awareness and education opportunities in our nation
2. Revitalize our work-based learning programs
3. Measure performance and involvement in workforce development when awarding construction contracts
4. Redefine how we measure the quality of our nation's secondary education system by career and college readiness
5. Increase the participation of underrepresented groups in Career and Technical Education (CTE)
6. Establish and expand collaboration between industry, education and government
7. Develop more balanced funding among postsecondary CTE versus higher education

Our work extends and transposes these categories for manufacturing and act as a mechanism for prioritization. The themes that emerged in our findings align with the policy suggestions put forth by NCCR. However, we argue that highest priority should be given to establishing partnerships between industry, academia, and government because these collaborations can act as enablers or deterrents for workforce development programs.

5.1. Changing Perceptions of Manufacturing

The first short term policy defined by NCCER aims to establish and strengthen career awareness by communicating "all career paths to students in secondary education and their parents" [35]. In manufacturing this policy aligns with changing the perception of the industry which is a significant goal in each of the workforce development programs discussed. From early education research we can posit that this type of outreach should not be limited to secondary education. Research has shown that early on industry representatives are main influencers in education and career decision-making processes [21]. The success of raising career awareness and delivering qualified workers is tied to collaborative efforts with academic institutions across all levels.

The NW Georgia Manufacturing Day is exactly about creating exposure to local manufacturing jobs and the skills required to be successful in order to change the stigmas associated with manufacturing careers. Yet, the reversal of the event format to an entrepreneurship panel in 2018 over the hands-on robotics experience in 2017 exemplifies the disconnect between industry and the next generation workforce.

To strengthen career awareness, students need to associate manufacturing with positive experiences reinforcing 21st Century skills like creativity and problem-solving. Education professionals need to be leveraged to create meaningful and engaging opportunities for the future workforce. In fact, the importance of experiential learning and the impact of preparatory STEM education is often underestimated by managers even though it is has been found to decrease costs associated with upgrades in industrial technology [7]. As a result, combined efforts of academia, industry, and government are necessary to successfully change the perception of the manufacturing industry.

Still, awareness is twofold; manufacturers need to be both involved and informed about the efforts surrounding workforce development to make an impact. There has to be a willingness from manufacturers to play an active part in shaping the workforce. Manufacturers must recognize that skill development begins in an academic setting. Although the required skills are driven by needs in industry, the primary acquisition of these skills occurs within the education system. Programs like the K-12 InVenture Prize act as a conduit for local industry to get involved in the community and the early stages of talent development. When assessing the effectiveness of pedagogical approaches to closing the skills gap researchers at Worcester Polytechnic Institute found that students are more than twice as likely to rate themselves as prepared in areas which employers do not agree; however, when academic projects incorporate industry, the employers' standards are likely to be fully met [18]. Getting more manufacturers involved in workforce development initiatives is a priority to support sustainability and growth.

An industry sector, such as manufacturing, is the strongest contributor to its own public perception but academia and government also play a role in shaping and propagating industry perceptions. COIM participates in manufacturing forums across Georgia, where manufacturers are quick to cite workforce shortages and the skills gap as major contributing factors to their lack of growth or success. Government entities like COIM need to be created to educate the manufacturing industry on ways to get involved. Additionally, academic institutions need to communicate in the appropriate forums to garner awareness, involvement, and support from industry. The direct results of which will help employers address their workforce issues in the long term.

5.2. Expanding Access through Local Models

Adaptations in program design towards more "local" models could assist in overcoming logistical challenges and enable increased participation from a more diverse and higher number of students. One of the NCCER long term policies is geared towards increasing participation of underrepresented groups [35]. The approach outlined relies on creating mentorships [35]. The impact of mentoring relationships can be deep, but the programs are not easily scalable. Mentorship programs rely on heavy recruitment strategies and are depend on each individual participant to accurately represent the industry. Additionally, the ability to reach under represented populations may be hindered because the mentor pool is not relatable. Manufacturing faces these challenges as well. One aspect of the K-12 InVenture Prize Summer Accelerator program is that participation is limited to those who can afford it and have a reliable means of transportation to attend. All three programs could be adapted to operate as more "local" models. As we experienced with the NW Georgia Manufacturing Day event, this requires significant support from local partners prioritizing collaboration once again.

Consider for example the GTMI-TCSG internship program, a localized, regional internship model would offer more flexibility and access. Universities throughout the state would offer internships to students from technical colleges within their regions. In the state of Georgia, Georgia Tech could continue to offer internships to the six technical colleges within its region, while Georgia Southern University could offer internships to technical college students at Savannah Technical College, Ogeechee Technical College and Southeastern Technical College. The number of days that technical college students are required to be at the university could also be reduced. Some of the internship project work could be performed by the student using the facilities and equipment at his or her technical college, under the guidance of a participating technical college instructor. This would reduce student travel time and cost, thereby reducing a barrier for students who are interested in participating. This model would require significant institutionalized support of a larger number of participating technical colleges and universities. It also presumes that the local university has the same need to fabricate parts to support university research, and/or prototypes to support local industry that Georgia Tech maintains.

Another potential variant on the program design is to replace the internship program with courses at the technical colleges that could deliver similar experiential learning opportunities. An example of such a course at the university level is Georgia Tech's sophomore-level Mechanical Engineering (ME) design and build course, ME 2110, Creative Decisions and Design. ME2110 combines classroom lectures, hands-on training in basic fabrication processes, and the design, and construction of a functional mechatronic device. The class culminates in a competition between student teams as the ultimate test of their designs. Students in ME2110 attend two 1-hour lectures and one 3-hour laboratory session per week. The lectures focus on topics critical to the mechanical design process, including customer needs, functional requirements, design specification, and technical writing [8], while the laboratories focus on hands-on design, fabrication, assembly and testing.

In 2017 with support from COIM, Georgia Tech and the TCSG implemented a pilot program to develop a course, similar to ME 2110, at the technical colleges. Creating the course would allow a significantly larger number of technical college students to participate, relative to the internship program, while eliminating the need for students to travel, and eliminating heavy reliance on a university partner's fabrication needs, facilities, and staff. The course could also be duplicated at several technical colleges around the state. The technical colleges offer a unique environment for such a course due to the availability of fabrication equipment and laboratory facilities, and the hands-on project-based learning environment that already exists. In addition, the opportunity to assembly multidisciplinary teams of students enrolled in a number of manufacturing related programs, such as Precision Machining and Manufacturing, Electronics Technology, Engineering Technology, etc., creates team dynamics that students will encounter in their future careers in manufacturing.

The first phase of the program involved a faculty member from WGTC travelling to Georgia Tech once per week for a semester to observe and co-instruct a studio session with a Georgia Tech faculty member and graduate teaching assistant. The co-instructor from WGTC shared educational and mentoring responsibilities, however, the non-studio time responsibilities (e.g., grading and office hours) remained the responsibility of Georgia Tech. The planned second phase of the program will be to invite faculty members from additional TCSG schools to participate. The goal of Phase III will be for Georgia Tech faculty to share all ME 2110 curriculum materials with the participating TCSG faculty members so that they can develop and implement the course at their respective technical colleges.

Developing opportunities at local levels increases awareness of manufacturing and allows for incremental growth. A similar approach is being adopted to expand the K-12 InVenture Prize program led by the Georgia Chamber of Commerce [8]. We anticipate seeing changes in the breadth of participating schools resulting in increased interest in the K-12 Summer Accelerator program. In the future, the outcomes of this expansion could validate our prioritization of collaboration amongst industry, government, and academia.

5.3. Increasing Collaboration through Funding

The downfall of many efforts to close the skills gap in manufacturing deals directly with the financial ability to support and sustain workforce development initiatives. The conclusion of the TCSG-GTMI Internship program was due directly to a lack of sustained funding. Additionally, COIM has covered all expenses associated with the NW GA Manufacturing Day event for 2 years in a row. The participating schools have dedicated time and transportation as well as donating space, but industry partners and other government partners continue to take a back seat.

One mechanism for achieving greater collaboration and engagement from academia, industry, and government is creating a shared funding model. Linking funding to collaboration targets two of the NCCER policies and addresses many of the challenges we discovered within each program [35]. It is important to recognize that funding does not guarantee an invested contributor, but it can be a mechanism to encourage active participation. As an example, a financial model could be considered in which a group of local manufacturers, local government, and state government share the cost of the program to maintain the necessary level of funding. This is a way to establish collaborative initiatives and create more balanced backing. Leveraging partnerships addresses the barriers surrounding funding, collaboration and support and the local model provides the opportunity to expand accessibility.

The incentives for each entity are clear. Local industry would benefit from a larger pool of higher skilled graduates thereby reducing its training burden, local government would be supporting workforce development in its region, and the state would benefit from offering a higher skilled workforce for its current and future manufacturers while the universities benefit from serving the community through support of workforce and economic development. Beyond funding, strong institutionalized support from all three entities would be necessary to encourage the participation of prospective students and manufacturers and encourage and incentivize sustained participation.

6. Conclusion

The complexities of workforce development are entangled with technology, education, and organizations. Recognizing these intricacies, it makes sense that representatives of each piece need to be involved in the constant evolution of defining and delivering new skills to the next generation. COIM is uniquely positioned to enable these types of collaborations within the education system by bringing together industry, academia and government organizations to promote hands on learning and change the perspective of traditional manufacturing.

By removing the boundaries of traditional classroom environments, the programs discussed in this paper exemplify innovative ways to approach short and long term initiatives to equip the next generation workforce. The rapidly changing landscape, enabled by digital technology, escalates the need for different approaches to blend experiences and new skillset requirements for workforce development. It is imperative that as we progress towards visions of the smart factories we must also continue to reimagine what future skills are going to be needed and ways to effectively deliver those skills.

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