STEM initatives in K-12 public education:

A review of innovative practices in the US state of Oklahoma

Keith Ballard
Department of Educational Leadership and Polciy Studies
University of Oklahoma
Tulsa, Oklahoma
keithb@ou.edu

***Abstract*—This innovative practice paper presents initiatives in the US state of Oklahoma that seek to link STEM education in K-12 public schools to post-secondary programs. In recent years, government agencies in Oklahoma have spearheaded numerous collaborative partnerships among secondary schools, career and technical institutions, and community-based organizations. The primary goal of these partnerships has been to provide coordinated education and training for students in STEM in ways that can increase the numbers of students graduating post-secondary institutions with advanced degrees and certifications in computing and engineering fields. This presentation examines innovative programs in Oklahoma that have unfolded through collaborative partnerships in recent years by exploring new curricular designs, experiential learning initiatives, capacity-building investments, and organizational restructuring that have undergirded school, university, and community partnerships in STEM education in Oklahoma. These programs not only attempt to provide high-quality learning experiences but also aim to support student transitions to post-secondary institutions. This presentation considers preliminary research on the academic, social, and economic outcomes for these programmatic innovations and considers what lessons can be drawn from these initiatives.**

Keywords—computing and engineering education, STEM, pre-engineering models

I. BACKGROUND

In the United States, over one million computer-programming and engineering positions are expected to go unfilled in 2020 [1]. The pressing need for greater expertise in computing and engineering fields has placed considerable pressure on public schools to provide stronger content, training, and hands-on experience in these areas. However, while many policymakers across the United States have attempted to bridge the skills gap by expanding career and technical education, this training often provides only a foundation for future work in high-skills careers in computer-programming and engineering [1]. As a result, many students do not transition successfully to post-secondary institutions and this situation appears to contribute to the mismatch between supply and demand in computer and engineering fields [2].

The US state of Oklahoma has placed considerable emphasis on preparing students for careers in computing and engineering. It has become a forerunner in STEM education in the United States. Following from numerous state and local initiatives, Oklahoma's Department of Career and Technology Education now oversees STEM programs at 29 post-secondary technology centers, 394 K-12 school districts, 16 "high skills" centers, and 32 adult education centers. Many of these programs have an evidence-informed focus on providing students with in-depth experiences that build competencies needed for advanced post-secondary training in computing and engineering fields [3]. Evidence indicates that bridging educational content early on can help to increase successful transitions to post-secondary institutions, and thereby, increase the supply of qualified labor [4].

Although initiatives are occurring across the state of Oklahoma, the Tulsa Metropolitan Area, the state's second largest metropolitan area, has been particularly active in developing school, university, and community partnerships aimed at producing computing and engineering graduates. In Tulsa, to build STEM programs, partnerships with local school district officials, career and technical education personnel, and state and local government officials were formed. These collaborative groups combined expertise and resources to embedded programs into local high schools that provide hands-on STEM training for students. These programs also allow students to spend time working both in the field and in the classroom. As detailed below, these programs emerged from the forging of formalized partnerships among multiple stakeholders.

Preliminary results of STEM programs appear to be largely positive in Oklahoma if assessed based on growth in participation [5]. Currently, nearly 50 percent of all students in Career and Technical Education in Oklahoma have a STEM focus. Oklahoma's efforts to support STEM and STEM-related career clusters represented 47 percent of all Career Technical Education concentrations in high schools in 2016-17, and comparatively, the U.S. average was only 35 percent [6]. Additionally, data from the US federal government indicates that eight years after graduation, the median annual earnings for Career Technical Education students were higher than that of their relative peers and that career and technical education students have a high rate of full-time employment and greater economic impact than than their relative peers graduating from non-STEM tracks [6]. While rigorous empirical analyses examining the longer term effects of programs in Oklahoma are needed, initial descriptive results are promising.

II. INITIATIVES IN OKLAHOMA

A. Tulsa Technological Center's Pre-engineering Academy

Tulsa Technological Center's Pre-engineering Academy is one the state's most important initiatives. The program aims to smooth the transition between secondary and post-secondary institutions by linking together curriculum, instructional methods, and experiential learning between the secondary and post-secondary levels. One of the Pre-engineering Academy's hallmarks is its Project Lead The Way (PLTW) component, which allows second-year students to take Introduction to Engineering and Principles of

Engineering at a post-secondary technological center. PLTW's Engineering Pathway utilizes a project-based approach to engage students in solving real-world problems using industry tools and software. Ten large school districts in the greater Tulsa Metropolitan Area are participating in this program, which serves a large proportion of secondary students in the region. The model also includes opportunities for participation in a pre-engineering academy for third- and fourth-year secondary school students. Initial descriptive evaluations of this model indicate that these programs have helped to smooth the transition to post-secondary engineering programs in the state [7].

In addition, the Pre-engineering Academy provides unique opportunities for students to engage with post-secondary instructors through hands-on projects and experiential learning projects. Students are given ongoing counseling to help prepare them for post-secondary coursework. Counselors schedule student development days to invite college recruiters and advisors, engineers from industry, and various technicians from a multitude of disciplines to interact with the students and share both academic and professional experiences. Students make secondary school to college transitions by meeting students from other schools within the Tulsa Tech district boundaries and working collaboratively with them. Students are given opportunities for leadership, and many compete in VEX robotics tournaments, as well as state and national Technology Student Association competitions.

At the Pre-Engineering Academy, this mission is achieved through preparing students for success in engineering majors at four-year universities. The students' plan of study for high school juniors and seniors at the Pre-Engineering Academy requires students to take one rigorous math or science course, such as: Pre-Calculus, AP Calculus AB or BC, Chemistry, AP Chemistry, AP Biology, Physics and AP Physics in addition to two Project Lead the Way (PLTW) Pre-Engineering courses. These two courses may be Aerospace Engineering, Civil Engineering and Architecture, Computer Integrated Manufacturing, AP/PLTW Computer Science Principles, AP/PLTW Computer Science A, Cyber Security, Digital Electronics, Engineering Design and Development, Introduction to Engineering Design, and Principles of Engineering.

B. Career and Aerospace Academy

In another collaborative partnership, Tulsa Public Schools and the Tulsa Technology Center designed a Career Academy and an Aerospace Academy. The Career Academy helps underrepresented students complete their high school coursework and provides training opportunities to enter the computing and engineering fields. The Career Academy has shown considerable success rates related to student attendance and nearly half- point rise in grade point average (GPA), which has been credited to higher levels of academic engagement among participants. Through the Aerospace Academy, located at the Tulsa Technology Center Riverside Campus, students incorporate a full day of academic and technical STEM training in either an aviation or information technology focus. Students earn the academic credits needed to graduate with their classmates, while also completing the training to begin a career in the aerospace industry. The establishment of this academy was not only a product of partnerships between secondary and post-secondary institutions but also included collaborative work with the mayor's office from the City of Tulsa.

This partnership between Tulsa Public Schools and the Tulsa Technology Center preceded the development of coordinated STEM courses that were devised and offered in Tulsa Public Schools. These expanded programs include Pre-Engineering at three major secondary schools. The original vision of embedded STEM programing now includes Foundations of Manufacturing at two large secondary schools in Tulsa. The embedded programs offer students the opportunity to gain hands-on experience even if their schedule does not allow for half-day training options at post-secondary locations.

The Engineering and STEM programs that were embedded at Tulsa Public Schools in partnership with Tulsa Technology Center, are now in place and also were the Foundation for programs that are now fully implemented in Tulsa Public Schools. The partnership with Tulsa Technology Center included Foundations and Principles of Engineering developed in partnership with Project Lead The Way. The initial partnership between Tulsa Technology Center, and Tulsa Public Schools designed a half-day STEM Academy where students studied advanced calculus and advanced physics courses along with civil and aerospace pre-engineering and advanced computer science courses. Descriptive assessments of these programs suggest they support post-secondary success in computing and engineering education [9, 10].

C. Curricular and Pedagogical Initiatives in STEM

In 2007, Tulsa Public Schools commissioned senior staff to re-design programming to include an emphasis on STEM and hands-on training for those students [6]. These offerings include expansion into three secondary schools in the district. The program at one of these schools is a stand-alone program under the direction of a former NASA engineer who was teaching math and science courses at the school. Consequently, a program was started first at this high school, and later followed by a larger and more inclusive middle school program. The middle school program has been the only public school for the past three years to place in the top 20 at the National Sea Perch underwater robotics challenge and the program at the high school excels at the National First Robotics Tournament annually, winning awards each year. This program was an integral part of the development of the Tulsa Regional STEM Alliance and TPS still holds a seat on their board to this day. This alliance offers STEM programming for free with the mission of building broad, deep, and innovative STEM pathways. The eventual goal is to reach 50,000 students annually. Programming includes math mentors, engineering games, summer camps, and training in coding.

To develop a five-year STEM plan, Tulsa Public Schools ensured that every student had at least one STEM activity or program each year through grade-level STEM experiences. Through the development of this plan, a STEM coordinator was employed in the school district to manage programming and the development of STEM experiences. In second grade, for example, students created aquaponics systems while fifth grade student built solar ovens. Each of these experiences were tied to curriculum standards and included a partner in the community [8]. For example, the second graders all visited Camp Loughridge to experience an aquaponics system.

D. *Structural investments in STEM*

Northeast Oklahoma has seen a considerable rise in manufacturing in recent years. In this region, the Industrial and Economic Development Authority in Claremore, a suburb of Tulsa, performed an economic needs study. It found that local industry required a larger pool of graduates trained in computing and engineering. Evidence also indicated misconceptions among local families and students about future opprotunities in computing and engineering careers. Students from the area were unaware of local career opportunities with a high level of income. To address this issue, the Industrial and Economic Development Authority in Claremore worked with local schools to provide training and information sessions to students and their families on employment opportunities in engineering, computing, and other manufacturing careers, such as welding, technical maintenance, computer-numerical controllers, quality control, and safety.

Engaging students while they are in secondary school may provide them with the opportunity to access and take advantage of concurrent courses in higher education institutions. However, to make the most of these prospects, students must be aware of the educational and career path demands from area industry. To support this objective, the Industrial and Economic Development Authority in Claremore has begun to aid school districts' ability to access and fund curriculum, implements, and locally-based industry experts related to STEM programming and labs.

In the region, there are seven K-12 school districts, one K-8 district, as well as a career tech and higher education institution. These districts serve approximately 14,000 students. Each of these institutions is vastly different, with grade class sizes varying from 30 to 300 students. The region spans from a small urban municipality to extremely rural, agriculture-based communities. Socio-demographically, each district is relative to the volume of industry in the area. For example, three districts have 100 percent free and reduced lunch student populations; whereas, one has a 23 percent free and reduced population. Additionally, the external funding fluctuates as some schools realize extensive support though an organized school foundation, while others rely solely on state support or donations from private industry. These differences lead to significant variations in students' educational experiences and opportunities. While one may have access to pre-engineering courses on-site, others may not even be aware of the field or have the educational experience required to enter a four-year university in a STEM field.

Historically, funding for area STEM labs has been limited. The local Industrial and Economic Development Authority in Claremore has devoted finds to partnering with local high schools to develop individualized STEM programming and lab infrastructure. To achieve the capital needed for the labs, local Industrial and Economic Development Authority in Claremore is attempting to expand these projects by approximately $3,000,000 so that each institution will have an on-site lab. These funds will look to address district shortages. This can include constructing labs, purchasing curriculum and equipment, as well as potentially offering educator fellowships for lab instructors. The volume of capital support each district receives will not be equivalent; instead, it will aim to meet the district on a needs-based level.

In approaching this project local Industrial and Economic Development Authority in Claremore is aiming to gain access to outside capital that enables rural and suburban schools to have a sustainable funding source for STEM curriculum that supports future careers in computing and engineering education. One of the most critical objectives in this effort is to expand opportunities to all students regardless of their geographic location or socioeconomic status. The theory of action is that there is untapped potential that can be part of increasing computer and engineering graduates. Enhanced support in low-income areas is expected to foster growth in computer and engineering graduates, but at present, little empirial research has investigated the effects of these strategies. In the years to come, scholarly evaluations will be needed to determine if these efforts have produced as hoped.

III. Future Directions

In 2015, the voters of Tulsa approved a bond issue, in the amount of $415 million with an approval rate of 86.6%. This bond included 4.5 million dollars to build a STEM center and another half million dollars for STEM resources. At about the same time as the bond issue was passed, a local philanthropic organization was developing The Gathering Place, a park that aimed to serve as a cornerstone for the vibrant community of Tulsa, while improving social, economic, and environmental sustainability. The goal of The Gathering Place was to create a gathering space that would serve as a recreational, civic, and cultural destination. The park is presently constructing a new STEM center with five dedicated classrooms outfitted as STEM labs and complete with movable walls and furniture. The center is designed to allow hundreds of different configurations for different group needs as well as full access to a hands-on science museum in the park. Recently, the Tulsa has also become one of the finalists for a new Tesla factory.

In Northeast Oklahoma, officials are target STEM programming and attempt to incentivize youth to pursue university training in STEM fields. In March of 2019, the citizens of Claremore passed a $41 million bond issue, that placed a major emphasis on STEM programs. The bond issue passed at an 87% approval rate. When school starts in 2020-21, all four Claremore Elementary Schools will have new STEM labs. The labs will emphasize science, technology, engineering, and math, and will cost $600,00 collectively. The labs will be instructed by STEM trained facilitators and will focus on critical thinking, problem solving with creative solutions, strong collaboration, and projects that reflect individual interests in STEM. Specifically, the labs will include Circuitry, Digital Media Communications, Robotics and Control, Technology, Software Engineering, Computer Graphic and Design, Mechanics and Structures, Scientific Data and Analysis and Sustainability. Every student in grades K-5 will experience the Innovation Labs with longer and more intense rotations for grades 3-5. These labs will focus on creating opportunities for all students, particularly those from low-income backgrounds. The stated goal is to inspire future inventors, engineers, entrepreneurs, while motivating students for a lifetime of learning. To carry out this STEM program, Claremore Public Schools, utilizing funds from the successful bond issue will construct Innovation Labs for students in grades 6-12. Beginning in the 2020-21 school year, Claremore Public Schools will construct a $9 million Innovation STEM Building. Included in the 29,000 square foot building will be Robotics, Digital Media Production, Bio-Med, Computer Art Design, and Computer Science. The building will open in the school year 2021-2022. High School

and Jr High teachers will begin their training in the Summer of 2020.

IV. Conclusion

The US state of Oklahoma has been at the forefront of efforts to train students for careers in computing and engineering. This innovative-practice paper reviewed partnerships between secondary schools, post-secondary institutions, and community partners that have sought to develop STEM programs by linking together curriculum, instruction, and experiential learning. For students seeking to major in computing and engineering, the pre-engineering academy outlined in this paper may be one of the most promising initiatives that can increase successful transitions to engineering programs in post-secondary institutions. Yet, while much activity and investment is occurring in Oklahoma, little scholarly research has been done to examine the effects of these various initiatives. Evaluations of these investments will be valuable toward understanding what has worked and what has fallen short of expectations.

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