# Impact for Female Students of an Integrated STEM PBL Summer Curriculum on Content Knowledge Mastery and Post-Secondary Matriculation

Robert M. Capraro, Mary M. Capraro, Sandra B. Nite, Luciana R. Barroso, ‘Chon Brooks
Aggie STEM
Texas A&M University
College Station, TX, USA
rcapraro@tamu.edu, mmcapraro@tamu.edu, snite@math.tamu.edu, lbarroso@civil.tamu.edu, chonbrooks@tamu.edu

***Abstract*—Secondary STEM learning is paramount to post-secondary success, and understanding what interventions preserve STEM interests and how that translates into post-secondary matriculation are issues being faced nationally. Two groups of female students were randomly assigned into STEM Opportunities and Content Mastery. The first group was designed to focus on building STEM experiences and Science, Technology, Engineering, and Mathematics content through engineering design applications (STEM Opportunities group). They had real-life engineering experiences and developed content knowledge in relation to their projects. The second group was designed to receive targeted content instruction and advanced support for learning in the STEM fields without engineering experiences or hands-on activities (Content Mastery group). Both groups met for 4 hours during the summer for 4 weeks. The STEM Opportunities group had the greatest post-secondary matriculation with 82% as compared to 54%. Of the 82%, 13% entered trade school to obtain a "hidden" STEM job, 54% entered community college, and 33% were admitted to a university. Of those admitted to either community college or university, 56% were admitted to a STEM major. For the Content Mastery group, 25% entered trade school, 44% entered community college, and 31% were admitted to a university.***

***Keywords— project-based learning; student-centered learning; secondary informal education; STEM enrollment***

## I. INTRODUCTION

### *A. STEM Workforce*

There is a strong need to strengthen the STEM (science, technology, engineering, and mathematics) workforce in the United States. Even though school curriculum determines a student's preparedness to take up a STEM related career, persistence in STEM is influenced by out-of-school factors such as attitudes of peers, family members, and the individual. A plethora of informal learning environments are available for STEM learning, such as summer camps, after school programs, museums, environmental education centers, and community based events. Project-based Learning (PBL) is an inquiry-based teaching approach where the learner is provided with a well-defined outcome but limited information about how to accomplish the task (ill-defined task) [1]. The approach is student-centered and empowers learners to conduct research, integrate theory and practice, and apply new and prior knowledge and skills to develop a viable solution to a specified problem. This active learning strategy engages students in problem solving that was substantially different from the traditional classroom and emphasizes the use of knowledge in a context.

Economic progress of any country is highly dependent on STEM innovation. The founding fathers of the United States understood this, as is evidenced by the Constitution’s giving of the authority to grant patents to inventors to “promote the progress of science and useful arts.” The growth of higher education accompanied by an increase in STEM degrees impacted the economy positively, with new technological developments in industry that strengthened the economy [2]. In 1945, a report to President Roosevelt was instrumental in establishing the National Science Foundation, which continues to emphasize the importance and continued need for STEM education. President George W. Bush picked up the mantra, establishing the American Competitiveness Initiative to increase STEM professionals. President Obama followed with initiatives designed to improve K-12 STEM education [3].

Economists have identified a need for STEM professionals far beyond the current rate of production, an increase of about 1 million more over the next 10 years. Such a goal would require the number of undergraduate degrees awarded to increase 34% annually throughout the decade. However, this level of increase has not been realized because the proportion of STEM degrees has fallen. A STEM degree is completed by less than 50% of students who enroll in college with the intent to earn a STEM degree [2]. In addition, women and minorities are still underrepresented among college graduates, constituting about 45% of the undergraduate STEM degrees while representing 70% of the college population [4][2].

By 2013, it was noted that 20% of all jobs in the United States were in STEM fields. Although there are many jobs that require a bachelor’s degree in a STEM field, there are also numerous jobs that require a high level of knowledge in one or more STEM fields and do not require a bachelor’s degree. As the number of STEM jobs increased, researchers recognized the existence of two STEM economies: 1) a professional STEM economy, and 2) a technical STEM economy, sometimes referred to as the "hidden" STEM economy [2][4]. The professional STEM workforce is located primarily in research universities and the corporate world and is a critical factor in keeping America on the cutting edge of technology and engineering developments. The technical STEM workforce may be less likely to be involved directly in invention, but they provide input on practical aspects such as design feasibility, cost reasonableness, and creation of new ideas [2][6]. Technical workforce jobs often require various specialized trainings as well as a strong background in mathematics, technology, and various areas of science. Approximately half of the available STEM jobs are accessible to this workforce, and they earn salaries about 10% higher than nonSTEM jobs that require an equivalent education [5].

All Americans can benefit from STEM knowledge because of the integral role to society that technology and other scientific products have. More proficiency in the use of such technological advances brings experiences to all ages of the citizenry that increases their abilities to contribute in a meaningful way to improve life for all members of society. Colleges and universities can alleviate the demand for a STEM literate workforce by providing a variety of entry points to STEM degrees as well as acknowledging and providing support to students in STEM-cognate fields [2].

### B. *Informal STEM Learning*

Formal education at the secondary and post-secondary levels has not provided the type of instruction that improves the skills researchers assert are necessary for solving 21st century problems. The STEM workforce needs employees who can meld creativity with STEM content knowledge as they collaboratively solve nonroutine problems [4]. However, formal education is only one-way people engage in STEM learning activities. Informal venues such as museums, parks, after school programs, and summer programs have expanded into vitally important sources of STEM education [7]. These informal STEM learning groups are less constrained than formal education, allowing teachers to engage students in real life problem situations. They have increased interest in STEM fields and understanding of STEM content, as well as reduced the achievement gap between high and low socio-economic students. There are three criteria that were identified for effective programs: 1) engaging by providing real life experiences in a supportive learning group, 2) responding to interests of students by being meaningful, and 3) making connections within and outside the school, home, and other settings [7]. The need for informal STEM learning opportunities to supplement formal education has remained high, and these venues have promoted integrated content learning and inquiry-based experiences. However, a Nielsen survey showed that only 20% of households have children who have accessed afterschool STEM programs [4].

### C. *Project-based Learning (PBL)*

STEM education, whether formal or informal, had positive effects in terms of deeper content knowledge, STEM interest, and improvement of 21st century skills when inquiry-based instructional methods were used [8][9]. One such approach is project-based learning (PBL). Students are more engaged in the learning process when they are able to investigate authentic problems and persist throughout an engineering design cycle to work toward the best possible solution under the constraints given [10][11]. In PBL, teachers guide students through scaffolded instruction and coaching as they accept responsibility for their own learning [10]. Females found STEM activities more accessible and appealing when they involved creative solutions [12]. In a formal school setting in which STEM PBL was implemented, female mathematics and science scores increased [13]. Thus, STEM PBL is a teaching and learning model that encourages collaboration and creative exploration of STEM ideas throughout the process, which are characteristics of an educational model that fosters a more equitable learning opportunity for gender differences [12].

### D. *Theoretical Underpinnings*

The underlying learning theory upon which this study is built is that of active learning based on the original work of Jerome Bruner's Constructivist Learning Theory situated at the nexus of three other theories, (1) Cognitive Flexibility theory (Spiro), Conditions of Learning (Gagne), and Experiential Learning (Rogers). By cognitive flexibility, we mean the ability to spontaneously restructure one's knowledge, in many ways, in adaptive response to changing situational demands. This occurs when students engage in hands-on learning situated in complex tasks where there is no obvious convergent solution or solution technique. For Conditions of Learning, there must be an opportunity to practice developing new solutions to problems; to learn attitudes, the learner must be exposed to a credible role model or persuasive arguments. The students participated in learning communities where they acquired attitudes consistent with developing new solutions to problems with divergent solutions based on assumptions. Finally, by experiential learning we mean that students engaged in activities where they applied knowledge. An example is student learning about how wings function and how Bernoulli's Law applies to the way wings are shaped to allow planes to fly, taking into account that flat surfaces must be held firmly in place when air is forced under the wing. The nexus of these learning theories was used to produce a single unified experience that was all situated within constructivist learning or the building of one's own knowledge through active and engaged learning.

## II. PROGRAM DESCRIPTION

STEM-trained high school teachers, in collaboration with Aggie STEM, designed an informal STEM Camp. The teachers in the school wanted to focus on females and the special needs that are often ignored within the regular school program. The setting was an urban school with high poverty and generally low academic achievement. The student population of the school was comprised of 51% female, 55% Hispanic, and 23% African American students. The STEM camp was comprised of two strands: a) STEM Opportunities group and b) a traditional Content Mastery group.

The STEM learning opportunities were designed to build awareness of STEM professions, job expectations, salaries, and post-secondary requirements for attaining career and experiential learning activities in the core mathematics, science, technology and engineering subjects. The "hidden" STEM workforce was also addressed, and post-secondary training programs, certifications, and 2-year options were presented. Students engaged in active learning dealing with topics covered in electrical, civil, and mechanical engineering and mathematics and science topics covered in physics and physical science. The Content Mastery program was designed to address specific academic needs or common deficits in algebra, geometry, pre-calculus, physics, and physical science in a traditional textbook, reading, and response format.

Students were told that they would be randomly assigned to one of the two groups. However, the students were allowed to rank order their preference. They were told that the rank ordering was going to be used to determine the proportion of students randomly assigned to each group. Therefore, if 2/3 of the respondents chose the STEM opportunities then the STEM opportunities group would be comprised of 2/3 of the sample. The selection choice was nearly 50%, so each group was nearly equal. The random assignment process ensured that there was an exact probability of being assigned to one group or the other. There were 63 students in the STEM Opportunities group and 64 students in the Content Mastery group.

### *A. Intervention*

The intervention followed the same students for three years with summer informal education in 10$^{th}$ and 11$^{th}$ grades. The camp was two weeks long during the summer with on-going support throughout the school year. During the summer, the STEM opportunities group spent 4 hours each day engaged in a variety of activities including STEM PBL activities, learning about engineering disciplines, hearing from engineering professionals and professors, and engaging in research about the various STEM jobs including the "hidden" STEM workforce. This hidden workforce consists of jobs that require two or less years of additional training after high school. It is projected that nearly half of all STEM jobs are available to workers with two or less years of post-secondary training. These jobs are estimated to pay on average $53,000 per year. Considering that this average annual salary is 10% higher than jobs with similar educational requirements, pursuing one of these "hidden" STEM workforce jobs can provide a livable wage and a reasonable standard of living. Further, nearly half of the "hidden" STEM workforce jobs are in manufacturing, health care, and construction industries. Compare that to installation, maintenance, and repair occupations that constitute a mere 12% of all STEM jobs. There are many technical hidden STEM workforce jobs with new ones emerging all the time, for example, app designer, web designer, coder, and computer numerically controlled (CNC) operator. Additionally, while not truly considered STEM jobs, there are other blue collar or technical jobs in fields such as construction and production that frequently demand STEM knowledge [3].

Students were engaged with engineering design and learned to apply its principles to various projects. The informal projects included Bridge Design, Egg Drop, Robotics, Furniture Design, Water Purification, and Rocketry. Students chose only two from among the opportunities each summer. The activities lasted for two weeks, 2 hours per day per activity. Both groups participated in networking and support during the school year, some formal and others mostly informal.

The Content Mastery group spent 4 hours per day engaged in learning targeted to their learning deficiencies with the expressed purpose of helping students to be successful in upcoming courses, specifically, algebra, geometry, pre-calculus, physics, and physical science.

During the school year, the students met monthly for 90 minutes. The STEM Opportunities group participated in STEM seminars where they discussed their progress in STEM courses, talked about the difficulties they were facing, brainstormed solutions, explored nuances of STEM careers, and built learning communities and study groups around common STEM courses. Students autonomously formed informal study groups that met outside of the organized time and without teacher supervision or support. The Content Mastery group participated in content specific study groups where the focus was a common issue or deficit in one of their courses. Students had the opportunity to receive just-in-time instruction if they asked for help with difficult topics in mathematics or science that month. Students worked in teams during the years, but only a few students formed study groups primarily around physics.

### *B. Purpose and Research Questions*

The purpose of this study was to determine which type of informal intervention was most beneficial for female students. The research question was: Longitudinally over two years do female students who were in a Content Mastery informal STEM program do as well as students in STEM learning opportunities as measured by school content tests?

## III. METHODOLOGY

Data were collected to determine how an integrated STEM PBL experience delivered during the summer for two consecutive summers and with ongoing support to the same populations, would impact their content knowledge and post-secondary matriculation. The sample was 100% female, and they were randomly assigned to one of two groups. Either they were placed in the STEM Opportunities group or the Content Mastery group. Both groups met for 4 hours during the summer for 4 weeks. Both groups were 53% Hispanic. The STEM PBL group was 22% Black, 8% White, 6% Asian, and 11% other. The Content Mastery group was 24% Black, 8% White, 5% Asian, and 5% other.

The data were analyzed using 95% confidence intervals, effect sizes, and percentages. The 95% confidence interval is considered one of the best reporting strategies [14]. The reporting of confidence intervals (parameter estimates, differences in means and effect sizes) can be an extremely effective way to report results. Like effect size estimates, confidence intervals have been advocated for some time [15]. The data were analyzed using 95% confidence intervals for each group (STEM and Content) by each of the measured and latent variables. Interpretation of the representations for the confidence intervals was completed as described in Capraro [15][16] and Cumming and Finch [18]. This analytic method provides for comparison that limits inflation of TYPE I Error by using multiple univariate tests [19]. A statistically significant difference ($p < .05$) exists between groups, in this case when there is a 25% or less overlap of confidence intervals.Data were collected to determine how an integrated STEM PBL experience, delivered during the summer for two consecutive summers and ongoing support to the same populations, would influence their content knowledge and post secondary matriculation. The sample was 100% female, and they were randomly assigned to one of two groups. Either they were placed in the STEM Opportunities group or the Content Mastery group. Both groups met for 4 hours during the summer for 4 weeks. Both groups were 53% Hispanic. The STEM PBL group was 22% Black, 8% White, 6% Asian, and 11% other. The Content Mastery group was 24% Black, 8% White, 5% Asian, and 5% other.

## IV. Results

The STEM Opportunities group had the greatest post-secondary matriculation with 82% as compared to 54% of the Content Mastery group. Of the 82%, 13% entered trade school to obtain a "Hidden" STEM job, 54% entered community college, and 33% were admitted to a university. Of those admitted to either community college or university, 56% were admitted to a STEM major. For the Content Mastery group, 25% entered trade school, 44% entered community college, and 31% were admitted to a university.

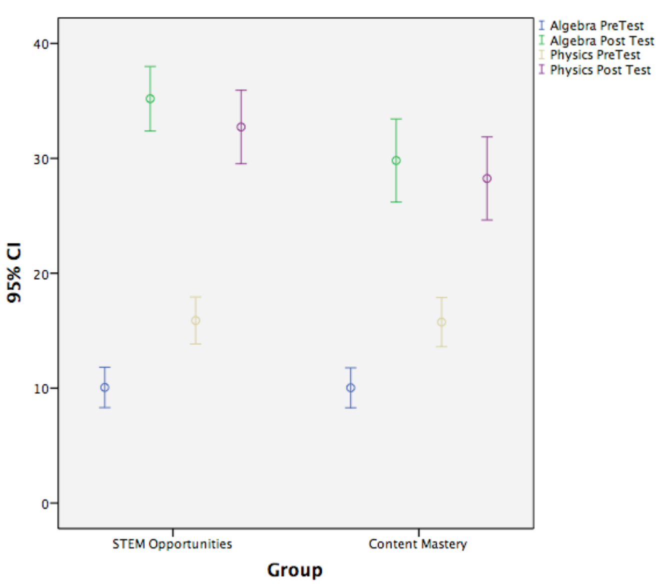


Fig. 1. Algebra and Physics Performance by Group

Performance differences between the two groups in knowledge of algebra and physics were starkly different (See Fig. 1). Both groups started in nearly the exact same points for both subjects: $\overline{X}$ =10.03 ≅ 10.06 for Algebra, STEM Opportunities and Content Mastery groups, respectively, and $\overline{X}$ = 15.89 ≅ 15.75 for Physics. The Cohen's *d* effect size for Algebra was 2.70 and 1.58 for Physics for the STEM Opportunities group. For the Content Mastery group, the Cohen's *d* effect size for Algebra was 1.74 and 1.05 for Physics. Both groups demonstrated large effects; given that this is a measure of knowledge before instruction and then, after instruction, this particular result parameter is not all that uncommon or remarkable. However, in comparing the performance of the two groups after the intervention the differences are striking as demonstrated in the post-test results. The STEM Opportunities group out performed the Content Mastery group on both Algebra ($\overline{X}$ = 35.19, 29.81 & SD = 11.16, 14.48), and Physics ($\overline{X}$ = 32.73, 28.25 & SD = 12.69, 14.48), respectively. When considering the value-added effect for the STEM Opportunities group, it was $d = .42$ for Algebra and $d = .33$ for Physics. Both effect sizes were strong and in favor of the STEM Opportunities group. The effect was indicative of nearly a one grade level difference in both Algebra and Physics on average. Another way to interpet the result was that for an average student who participated in the Content Mastery group and earned a "C", that same student would have earned a "B" if she had particiapted in the STEM Opportunity group.

The two groups diverged in their post-secondary matriculation, as shown in Fig. 2, with the STEM Opportunities group having a much higher enrollment in post-secondary STEM major matriculation at the conclusion of high-school. The STEM Opportunities group demonstrated a statistically significant difference (*p< .05)* compared to the Content Mastery group. The effect size was slightly more than 20%.

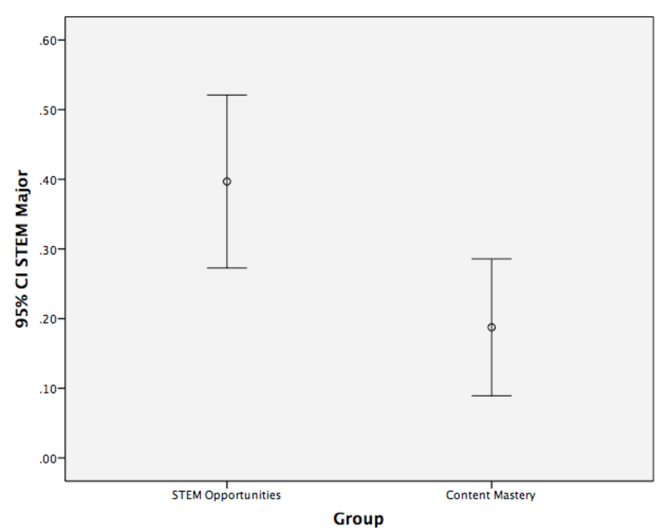


Fig. 2. Post-secondary STEM Major Matriculation

The STEM Opportunities and Content Mastery groups did not differ on post-secondary matriculation when considering all options including the "hidden" STEM workforce training, such as welding or certified nursing assistant, and other post-secondary training, such as trades, and service industry (e.g., cosmetology). However, when considering those options as related to the STEM sector, students who participated in the STEM Opportunities group exhibited a statistically significant difference from the Content Mastery group, as illustrated in Fig. 3.

To more thoroughly examine the differences between the two groups, ethnicity was considered (See Figure 4). The results represented were based on percentage because both groups were not exactly the same size for each of the ethnic categories. Matriculation for Asian females was not statistically significantly different between the two groups given that both 95% confidence intervals subsumed zero. However, there were statistically significant differences for Black and Hispanic females in the two groups with respect to matriculation into a STEM major. For Black females, more than two and a half as many Black females (considering percentages) from the STEM Opportunities group and about two times as many Hispanic females from the STEM Opportunities group matriculated into STEM majors.

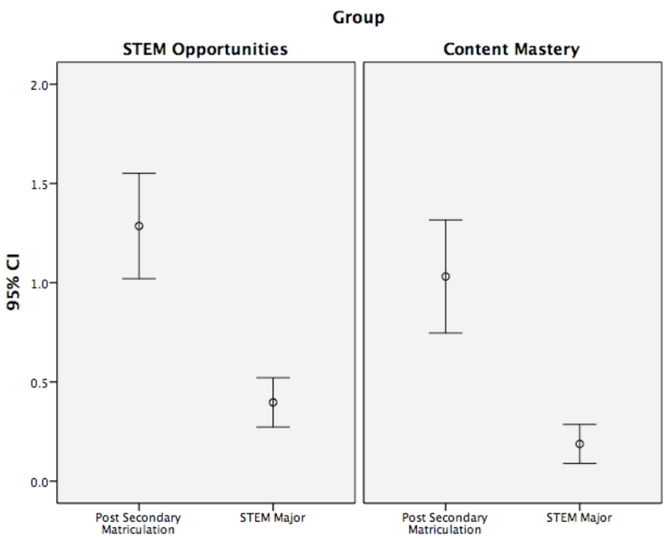


Fig. 3. Post-secondary Training Program versus a STEM Major or Emphasis.

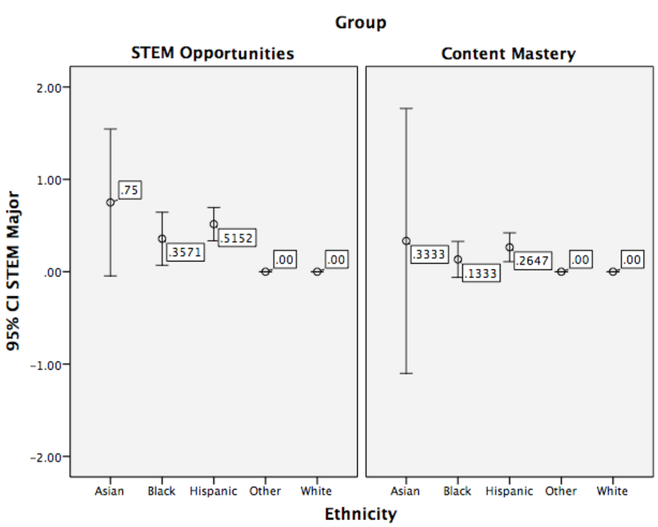


Fig. 4. Percent by Ethnicity Who Matriculated into a Post-secondary STEM Major

This is an important finding because matriculating into a STEM major indicated that they entered into a 4-year institution to pursue a degree from a university department representing one of the STEM fields. While there are many different majors and departments, it is distinct from two-year and shorter STEM workforce opportunities. Two important findings indicate that no White or Other females matriculated into a post-secondary STEM major. Historically, students from this school were underrepresented in post-secondary education in general. The obtained effects (dividing the smaller percentage into the larger percentage) resulting in 2.667 and 1.95 represent a very important practical difference in levels of acceptance.

## V. Conclusions and Discussion

An integrated and systematic STEM PBL experience was developed and delivered to the same population of female students during the summer semesters of two consecutive years, with activities occuring during the school year between the summers linking the camps and helping the students connect and transfer the knowledge and skills developed during the summer.

STEM Oppotunities positively impacted both the content knowledge in mathematics and science as well as increased post-secondary matriculation. While an increase in content knowledge in itself is a positive benefit for the students, the fact that the integrated STEM Opportunities group outperformed the Content Mastery group that had traditional content instruction is important. A common misconception is that less content mastery can be achieved through PBL because the teaching is not focused on the content (transmission of knowledge). But by engaging the students in meaningful experiences and guiding them to deeper understanding of the content, enhanced mastery of the concepts can be achieved even as additional learning outcomes are addressed. This was evident from the anticipated interactions of the learning theories underlying this study.

The experience also impacted skills and confidence as students began to take charge of their own learning experience, as indicated through the autonomous formation of informal study groups. The groups met outside of the organized time and without teacher supervision or support. Through the PBL experience, they had learned to work in teams to achieve a goal and to confront the boundaries of their knowledge, recognize gaps in that knowledge, and pursue different avenues for filling in the gaps.

As a result of the program, with stronger content knowledge and increased confidence and skills, the students in the STEM Opportunities group matriculated at a significantly higher rate into post-secondary STEM education opportunities similar to findings for university based programs [20]. The underrepresentation of females in STEM fields is a troubling issue that is not fully understood and is further complicated when females are also part of another minority group or from a low socio-economic background like the students who participated in this study. By using an integrated STEM PBL intervention with major immersive experiences during the summer and continued interactions during the year, a positive impact was made on this population, leading them to consider and pursue STEM educational opportunites. This is a critical component in addressing the underrepresentation that currently exists. While no data were able to be gathered to provide insights into the specific STEM majors students pursued, by increasing the overall pool of students considering STEM disciplines, it is expected that this will translate into a larger number pursuing engineering carreers.

The next step is to foster the development of a *STEM ecosystem*. The concept of a *STEM ecosystem* is the symbiotic interrelationships among stakeholders focused on workforce development. Those partnerships should include K-12 schools, technical schools, community colleges, businesses, and universities. Each partner is inextricably interwoven with the others charged with evolving and adapting to both internal changes and external factors facing their partners. *STEM ecosystem* can improve retention and increase the participation and persistence of underrepresented students in post-secondary education. The strong leadership that emerges from these collaborative groups fosters innovative educational interventions and provide for applied learning opportunities that make learning more meaningful. These teams can also offer a suite of support and wrap-around services at a lower cost and with greater flexibility.

Given the school success with its intervention and in tracking students, the next step for the school would be to develop their *STEM ecosystem* to support their former students and to help induct new students. The building of the partnership should be regional so that partners have easy access to each other and can build off each other's work of facilitating the transmission of successful ideas while building efficiencies. With a greater level of engagement from businesses, technical schools, community colleges, and universities, partners will build interest in secondary school students with clear paths to high paying employment.

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