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The Future is Here: Strengthening Engineering Education Pipelines from High School to University

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Dr. Zilouchian awards include: the lifetime achievement award (International Conference in Integrated System Design and Technology, 2023), the distinguished FAU Presidential Leadership Service Award in 2017 for his contribution to research and community engagement, College of Engineering Dean's Awards twice, and Excellence in Undergraduate Teaching Awards twice. He has published one book and more than 175 book chapters, scholarly journal papers, and refereed conference proceedings. He has supervised more than 22 Ph.D. and MS students to completion during his tenure, and taught more than forty-eight (48) different courses related to computer and engineering technology. He has been the associate editor of two Engineering and Computer Science Journals. He is currently active in several professional societies and editorial boards and is a senior member of IEEE and ASME and ASEE and AHSIE.

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Evaluation Paper: Strengthening Engineering Education Pipelines from High School to University

Abstract

This ***Evaluation*** *paper examines a multi-year strategic initiative designed to advance high-quality STEM education, particularly in engineering and technology—across high schools, community colleges, and universities. The momentum to strengthen these pathways is driven by national workforce demands, rapid advances in artificial intelligence, biotechnology, and quantum computing, and increasing global competition. Higher education institutions, in collaboration with industry, play a critical role in preparing a skilled and diverse STEM workforce. This paper presents a multi-year strategic plan implemented, a regional urban university that connects high school and community college students with authentic STEM learning experiences, resulting in measurable growth in STEM enrollment and graduation rates to meet workforce demands.*

Key engagement activities include maker labs, hackathons, virtual reality (VR) simulations, engineering systems exploration, "Brainy Days" with the Neuroscience Institute, and the all-day "Engineer Your Future" event. The university has developed a strong STEM Ecosystem of faculty and administrators who have successfully secured state, federal, and industry funding to sustain and expand these initiatives. Highlighted projects and lessons learned include the State of Florida CAPTURE Project and Careers in Cybersecurity programs; federally funded initiatives such as the Title III HSI STEM Articulation Project, NSF S-STEM Scholarship for the MS in Artificial Intelligence, NSF CyberCorps®: Scholarship for Service, and the U.S. Department of Education Promise Neighborhoods program with its emphasis on high school algebra; external partnerships such as Northeastern University's Women in Computing, and expanding industry and business alliances.

Faculty engagement within the South Florida STEM Ecosystem has established enriched pathways. and expanded opportunities for both high school and community college students. Together, faculty from Florida Atlantic University (FAU) and partner Community Colleges as well as STEM curricular supervisors from the two large, urban school districts collaborate regionally as part of these well-established STEM Ecosystems. These partnerships are further enriched by collaboration with local industry and business alliances.

In essence, the higher education institutions have collaboratively leveraged these initiatives and industry alliances, thus maximizing impact and ensuring a sustainable, inclusive STEM and engineering education pipeline.

Keywords: STEM Evaluation; STEM Education, Engineering Pathways, Workforce Development, High School–College Partnerships, Artificial Intelligence and Technology Integration, State College Articulation, Industry and Business Alliances and the Regional STEM Ecosystems.

I. Introduction

Career Trends Nationally: Powerful national indicators suggest that there may be more than 1 million new jobs in STEM fields by the end of year 2026, and, as a group, they will grow faster by a factor of 2x than the average for all occupations in the economy, according to recent projections by the Department of Labor, Bureau of Labor Statistics [1].

National labor projections indicate sustained growth in STEM occupations, with more than 858,500 new STEM jobs expected by 2028 and growth rates substantially exceeding the national average [1], [2]. Computing, cybersecurity, and software development represent particularly high-demand areas, with ~ 317,700 openings projected each year driven by technological advances across healthcare, energy, and data-intensive industries [3], [4]. Additionally, the Bureau has indicated that up to ~30% of the STEM careers will require proficiency in mathematics, with the level being above high school Algebra [4]. This is a daunting challenge given the non-stellar performance of Florida's 12th grade students on the National Assessment of Educational Progress [The Nation's Report Card. 2004]. Test results indicated that Florida 12th graders, on average, scored below the 2024 national average which, itself, was 3 points lower than the 2019 average [5].

Trends with Florida Students: Many Florida students who initially declare an intention to pursue STEM degrees actually fail to complete a BS/BA degree in STEM within six years. Many of these students are Hispanic. And, while they are one of the fastest growing demographic groups in America, they are one of the least represented in STEM post-secondary education and STEM careers [2]. Further, despite the growing demand for building a STEM workforce, Hispanics remain significantly underrepresented in STEM education and careers [3], presenting a critical challenge to national workforce competitiveness. Furthermore, nationally, the research indicates that while over 40% of entering postsecondary students express interest in STEM fields, nearly half fail to complete a STEM degree within six years [9], [10]. These challenges are often exacerbated by barriers related to prior academic preparation especially in mathematics, financial constraints, and limited exposure to authentic engineering experiences [11]–[20]. Addressing these barriers requires coordinated, evidence-based interventions that reach back into high school as well as across the span of secondary education, community colleges, and universities and with support from federal, regional and private funding sources.

This paper reports outcomes and lessons learned from CAPTURE and related federally funded initiatives, including a U.S. Department of Education Title III HSI project, the NSF S STEM Scholarship program, the Northeastern University partnership to advance women in computing, the US Department of Education's Promise Neighborhoods program and the Florida Atlantic University's Kelly-Strul Institutional Scholarship for local/regional Pell-Eligible students. Collectively, this growing portfolio of multi-faceted supports has enabled us to significantly strengthen engineering and computing pathways for Hispanic and low-income students through articulation, mentoring, scholarships, and early engagement strategies [27].

II. Motivation

Given the world-wide expansion of technologically based innovations (e.g., post-quantum computing, AI, cybersecurity), America is at a crossroad in terms of building a national labor force necessary for sustained growth in STEM occupations. From the continuing decline in students' academic performance across K-12, and current lack of completion of STEM degrees, and the growing population of underrepresented groups (e.g., Hispanic and low-income students), our University team in collaboration with members of our STEM ecosystem are addressing national workforce needs by strengthening educational pipelines that begin prior to university matriculation. Research consistently demonstrates that early exposure to engineering/mathematics/STEM concepts, coupled with structured academic and motivational supports, significantly improves student persistence and degree completion.

III. Program Design and Framework

In the following table the summary of different programs, their goals, years of implementation, and the impacts of the programs are presented. Due to the nature of different STEM initiatives, the table didn't provide the details of various tasks.

Table 1. Summary of Major STEM Pipeline Initiatives, Implementation Periods, and Impacts

Program	**Primary Goals**	**Years of Implementation**	**Key Documented Impacts**
CAPTURE Project	Develop seamless High School to Palm Beach State College (PBSC) and Broward College(BC) to Florida Atlantic University (FAU) engineering pathways-	2013– 2018	Increased STEM enrollment across pipeline; reduced credit loss in transfer; improved persistence for first-generation and Hispanic students; expanded access via online CS; strengthened workforce alignment

Program	**Primary Goals**	**Years of Implementation**	**Key Documented Impacts**
	Establish articulation agreements Provide mentoring and scholarships Expand online CS access Strengthen industry partnerships		
HSI Title III STEM Articulation (DOE)	Increase CS/CE/EE degrees among Hispanic & low-income students Refine gateway courses Implement structured mentoring & learning communities Develop longitudinal tracking Long-term Institutional Articulation Agreements	2016–2023	Improved gateway course performance; higher transfer efficiency; increased retention & graduation; strengthened engineering identity development; institutionalized data-driven improvement Written Agreement signed by Provost and/or Vice President
NSF S-STEM Scholarships	Support high-achieving, high-need STEM students	Five-Year Cycle 2021- Present	Very high completion rates; increased MS degrees in AI; strengthened research participation; improved communication and teamwork skills

Program	**Primary Goals**	**Years of Implementation**	**Key Documented Impacts**
	Increase MS completion in AI; integrate academic & Financial support		Scholarships based on un-met financial need
NSF CyberCorps	Prepare cybersecurity workforce for federal service Reduce financial barriers Create structured internship pipelines	Current 2024- Present	100% progression toward job placement in the federal government through the Office of Personnel Management (OPM) Strengthened cybersecurity workforce pipeline Sustained summer internship
Promise Neighborhoods STEM Ecosystem	Expand early STEM engagement Improve K–12 math instruction Provide on-going teacher PD for high school algebra and K-5 mathematics Strengthen community partnerships with focus on math	Current multi-year initiative 2024 - present	Increased after-school and summer opportunities to engage students in STEM activities through partnerships with community agencies (e.g., Boys & Girls Club, Urban League) Increased pass-rate in high school Algebra for all participating students, with focus on Title I students Students in K–5 and grade 9 STEM participation Increased teacher capacity AI- and technology-integrated learning
Regional STEM Ecosystem & Industry Partnerships	Align curriculum with workforce needs	2016 - Present	Expanded internships & employment pipelines Regional Broward STEM Ecosystem https://stemecosystems.org/ecosystem/broward-area-stem-ecosystem-base/

Program	Primary Goals	Years of Implementation	Key Documented Impacts
	Expand experiential learning Strengthen regional economic partnerships Build Synergistic Ecosystem among STEM organizations		Regional Palm Beach County (PBC) STEM Ecosystem (coxsciencecenter.org/pbc-stem) https://www.gflalliance.org/events/events/25/5801/02/detail/claim-your-future-showcase/2026/ Increased student motivation; Enhanced AI & cybersecurity workforce readiness

III.1 CAPTURE Project:

The CAPTURE framework is a comprehensive, multi-institutional model designed to accelerate student progression from high school through community college and into university engineering and computer science degree programs. The framework integrates seamless articulation agreements, aligned curricula, faculty-driven mentoring structures, industry partnerships, and early exposure to engineering practice.

Central to the framework is a streamlined admission and articulation process among three institutions Florida Atlantic University (FAU), Palm Beach State College(PBSC)and Broward College (BC) that includes Academic Flight Plans for each STEM course associated with the associate and bachelor's degree programs. These were jointly developed and publicly disseminated, enabling students to follow clearly defined academic pathways with minimal credit loss. Shared advising and rapid admission processing further reduced administrative barriers to transfer.

The implementation of the CAPTURE Program demonstrated the significant impact of the project on transfer students' success and degree attainment in Computer Science and Computer Engineering programs. The following chart provides the number of students who have transferred from PBSC and BC to FAU.

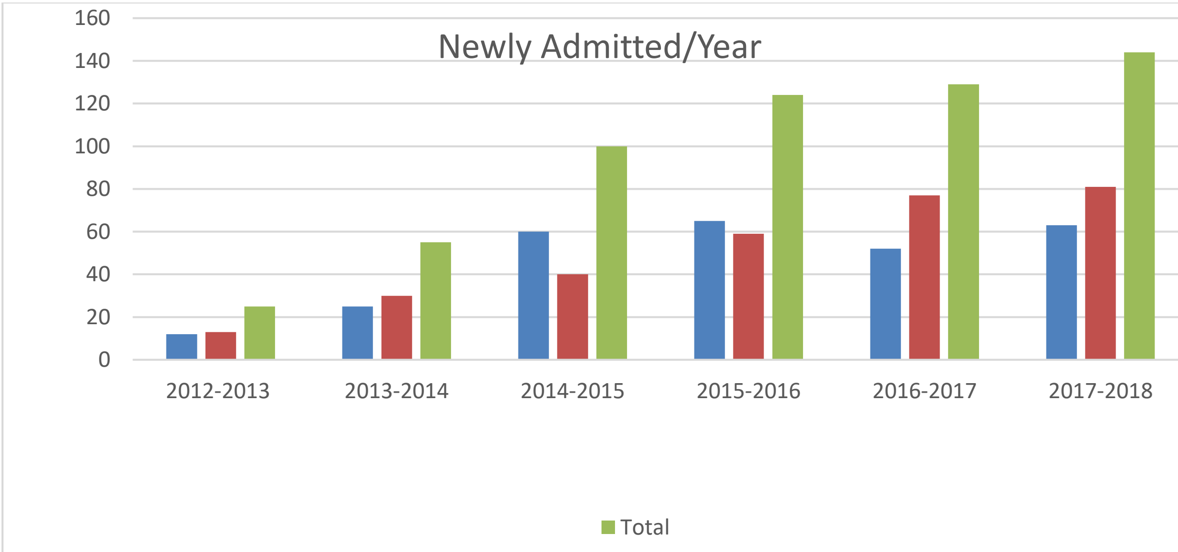

Figure 1: Number of Students Transferred from State Colleges to FAU

As shown above, the annual student pipeline from these two State Colleges has significantly increased from 25 students in the beginning of the project to 144 students in the fifth year (476% increase). We also had significant growth in the number of graduated students (66.4%).

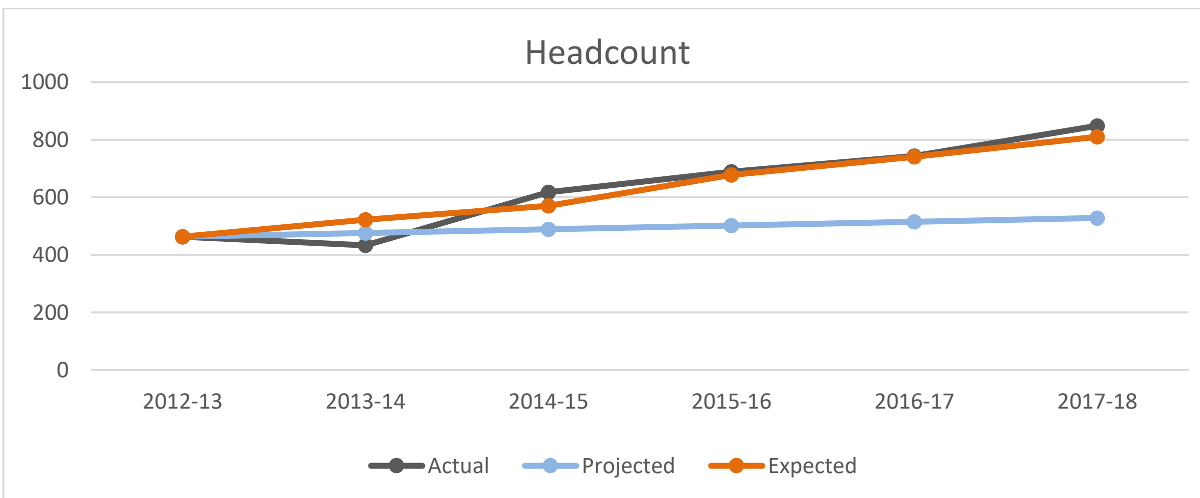

Figure 2: Student headcount for the EE, CE and CS students

The framework also emphasizes academic support through targeted scholarships, fully online program delivery options, and structured mentoring. CAPTURE scholarships and subsequent NSF-funded programs reduced financial barriers, while the development of a fully online Computer Science program expanded access for place-bound and working students. Mentoring structures paired students with trained peer and faculty mentors, providing academic guidance, career advising, and psychosocial support.

Industry engagement and K–12 partnerships extend the framework beyond postsecondary institutions. Advisory boards, internships, hackathons, and dual-enrollment engineering programs with regional school districts provided early exposure to engineering careers and reinforced workforce relevance. Collectively, these components form an integrated ecosystem that supports student persistence, degree completion, and workforce readiness.

In the following table the evidence of post-baccalaureate (completer) outcomes is presented for the last four years of the Program:

Table 2: Completer Outcomes in Targeted Programs		
Outcomes		Graduating Class
		2014-2018
Institution – Targeted Program Name – and CIP (Insert here)		
Total Graduating Class: Responded/Did Not Respond to Survey		
A	Responded to survey	385 & 66%
B	Did not respond to survey	201 & 34%
	Total	586 & 100%
Current Status of Responders		
1	Working full-time, not enrolled	231 & 60%
2	Working full-time, enrolled part-time	27 & 7%
3	Working full-time, enrolled full-time	17 & 4%
4	Working part-time, not enrolled	21 & 5%
5	Working part-time, enrolled part-time	5 & 1%
6	Working part-time, enrolled full-time	21 & 5%
7	Not working, not enrolled	39 & 10%
8	Not working, enrolled part-time	4 & 1%
9	Not working, enrolled full-time	20 & 5%
	Total	385 & 100%
Note: Total number should equal the number provided in row A.		
Unemployment Characteristic of Responders		
	Not working by choice	20 & 32%
	Not working not by choice	34 & 54%
	Not working no reason provided	9 & 14%
	Total	63 & 100%
Note: Total number should equal the sum of rows 7, 8, and 9.		
Location and Field of Work of Responders		
	Working in Florida	276
	Working In a field related to major	271
Annual Salary of Responders		
	$16,000 or less	68
	$16,001 to $32,000	47
	$32,001 to $48,000	63
	$48,001 or more	179

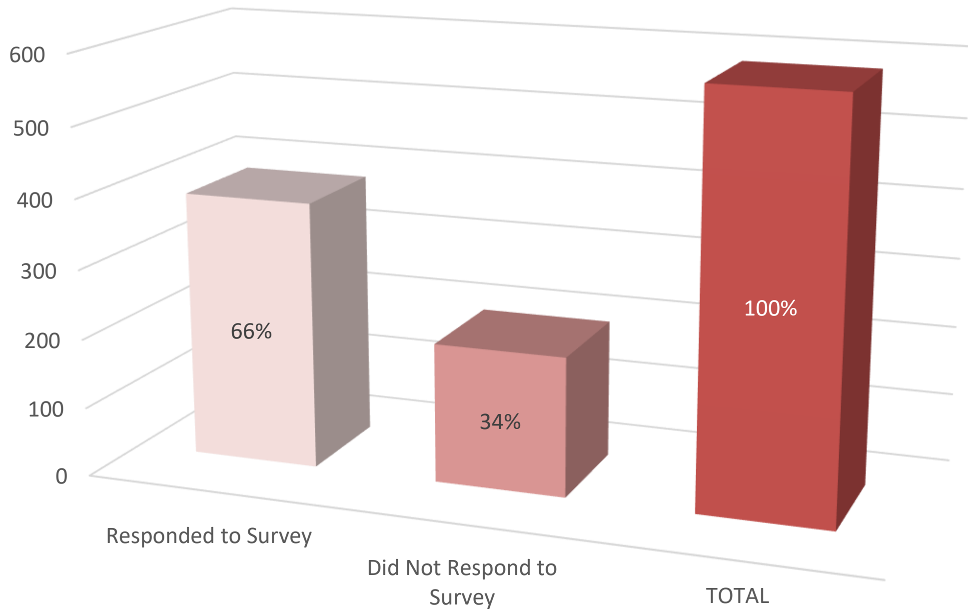

Figure 3. Graphical representation.

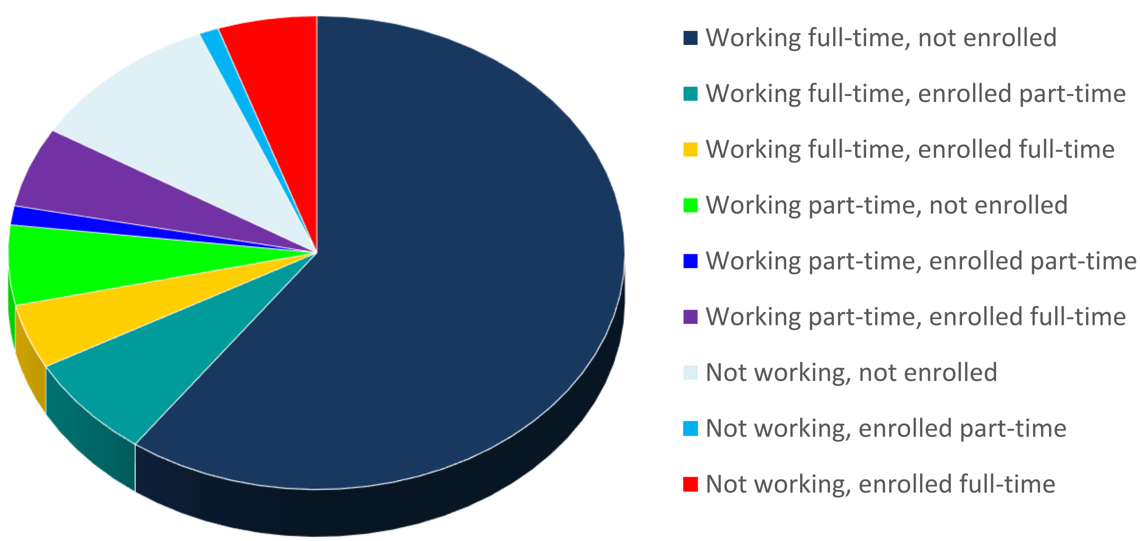

Figure 4. Graphical representation.

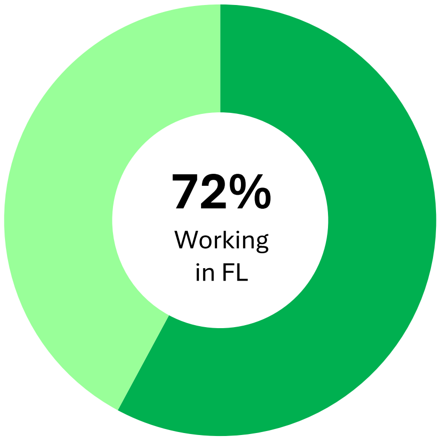

Figure 5. Location of Cohort

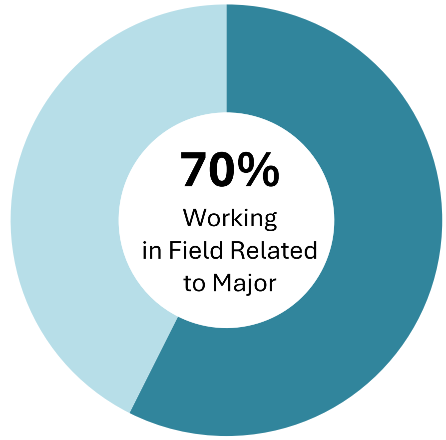

Figure 6. Field of Work for Cohort

III.2 HSI Title III Project

The CAPTURE team, in collaboration with the College of Education at Florida Atlantic University, proposed and was awarded a 4.45 million DOE Title III grant to boost the number of computer science, computer engineering and electrical engineering degrees awarded to Hispanic and low-income students. The articulation model was a key component and consideration for the DOE to provide the above prestigious federal grant to our three Institutions (FAU, PBSC, BC) for six years (2016-2022). As the CAPTURE program had focused on facilitating the transfer of students who began at 2-year state colleges (PBSC, BC) and transition to the 4-year university (FAU), the DOE Title III project established an articulation agreement with both partnering community colleges (see Figure 7) as well as having provided a platform for supporting low-income students with academic and motivational (e.g., self-efficacy, sense of belonging) supports which could easily be replicated.

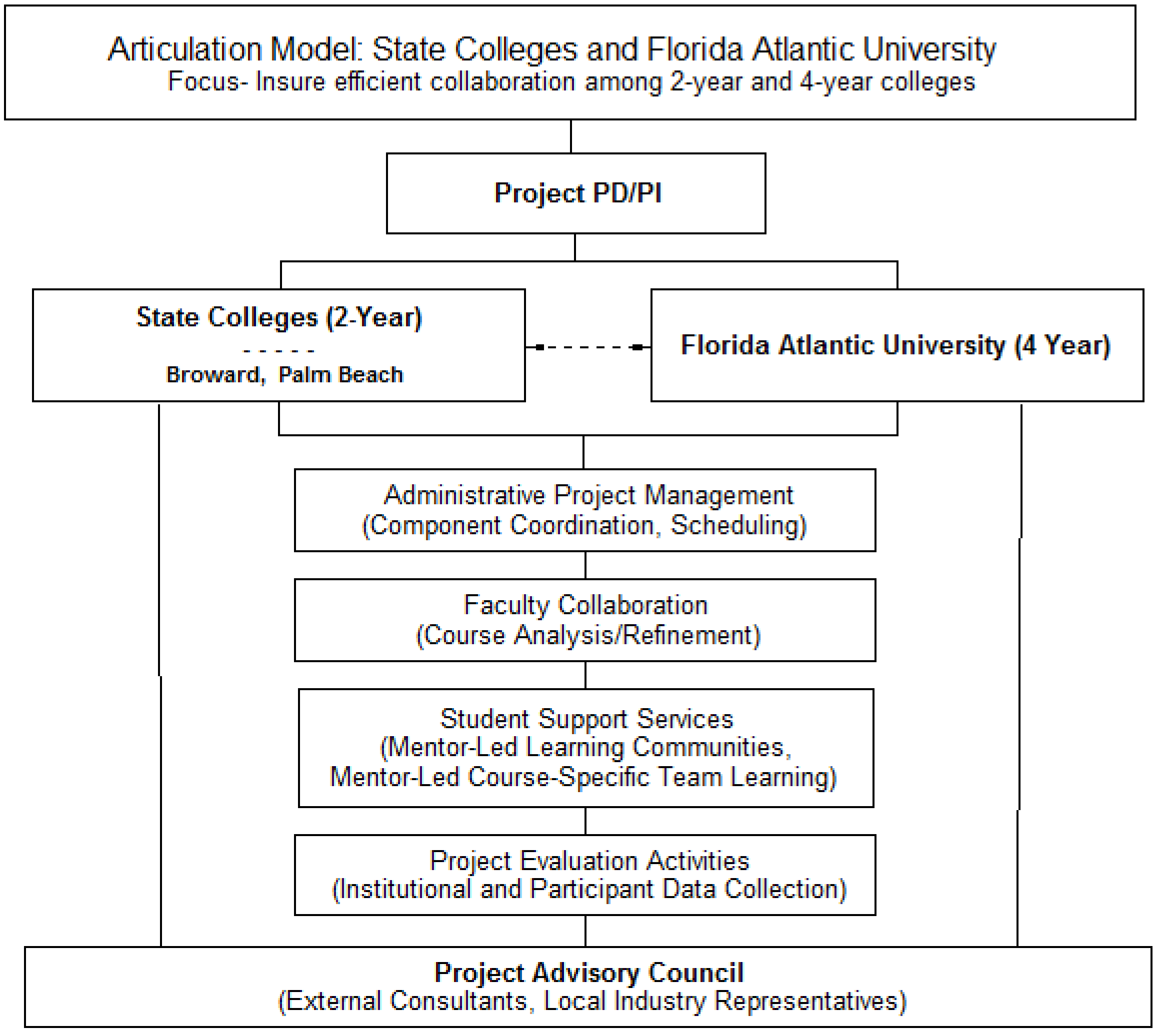

Figure 7. Graphical representation of Articulation Model

The articulation model presented in Figure 5 provides the structural framework for collaboration between the two-year State Colleges ([College 1] and [College 2]) and [University's] upper-division Computer Science, Computer Engineering, and Electrical Engineering programs. Within this framework, a coordinated set of interventions was implemented to strengthen student preparation, persistence, and transition across educational levels and institutions.

A foundational component was the implementation of the seamless admission process between the two State Colleges (PBSC, BC) and FAU . Shared advising and clearly defined academic flight plans enabled students to monitor progress toward degree completion and reduced credit loss during transfer. These structured pathways were designed to improve retention and graduation outcomes for students transitioning into FAU engineering and computing programs.

All data were obtained from longitudinal project College databases maintained by each State College. Controls were sampled randomly from State College student databases to insure demographic comparability of the HSI participants and controls for each Cohort. Data were processed using SQL software and analyzed statistically using SYSTAT.

To address academic barriers, the project implemented targeted curricular refinement of high-impact gateway courses, including mathematics (College Algebra through Calculus I) and Introduction to Programming. These courses were selected due to historically high DFW rates that disproportionately affect students pursuing computing pathways. Refinements focused on improving conceptual coherence and alignment with subsequent coursework, and with ongoing evaluation comparing student outcomes in refined versus traditional course sections.

A course-specific mentoring model complemented curricular improvements by providing structured academic support in gateway courses. Trained peer mentors emphasized conceptual understanding and the development of self-regulated learning strategies. Beginning in Year 2, university mentors were assigned to small groups of students on the two-year college campus, thus strengthening mentoring relationships and increasing the consistency of academic support.

The project also refined its student recruitment strategy to better align with pre-college and early college engagement goals. Recruitment efforts shifted from a primary focus on mathematics courses to the Introduction to Programming course, recognizing it as a stronger indicator of student interest in computing careers. Recruitment was further enhanced through the integration of learning community activities and a centralized web-based application process.

Table 3. FAU Trends in Enrollment, Retention, Graduation Rates (Overall Undergraduate)

FAU Institutional Data										
Total Fall Enrollment	**Pre-Grant Year**	**Year 1 2016-2017**	**Year 2 2017-2018**	**Year 3 2018-2019**	**Year 4 2019-2020**	**Year 5 2020-2021**	**Year 6 2021-2022**	**Year 7 2022-2023**	**Year 8 2023-2024**	**Year 9 2024-2025**
Fall-to-Fall Retention (%)	15673	15719	15917	16011	16228	16149	15400	15607	17192	17888
2-Yr Graduation Rate (%)	0.8628	0.8736	0.8817	0.8783	0.8812	0.8714	0.8668	0.8885	0.8902	
4-Yr Graduation Rate (%)	0.4222	0.4354	0.4609	0.4653	0.462	0.4658	0.4696	0.4857		
6-Yr Graduation Rate (%)	0.7173	0.7458	0.7664	0.7635	0.7574	0.7652				
	0.7772	0.7958	0.8096	0.8071						

Table 4. FAU Trends in Enrollment, Retention, Graduation Rates (FTIC Students)

Total Fall Enrollment (FTIC)	**3293**	**3041**	**2775**	**3148**	**3159**	**2960**	**2506**	**3045**	**3565**	**3366**
Fall-to-Fall Retention (%) (FTIC)	0.7742	0.8014	0.8262	0.8215	0.8241	0.8039	0.8094	0.8431	0.8449	
2-Yr Graduation Rate (%)(FTIC)	0.0157	0.0292	0.0273	0.0234	0.0366	0.0308	0.0423	0.0342		

A computer-oriented student learning community served as both a recruitment and retention mechanism. Learning community activities fostered peer connections, early engineering identity development, and exposure to computing careers through interactions with faculty and industry professionals. Participation was expanded in Year 2 to include all students enrolled in Introduction to Programming, broadening early engagement and strengthening the pipeline.

Finally, a multi-year longitudinal data system was developed to support program evaluation and continuous improvement. The database integrates student records across institutions, enabling tracking of academic progress from State Colleges through transfer and degree completion at the FAU . This infrastructure supports cohort analysis, comparison with matched control groups, and assessment of long-term program outcomes.

IV. Results and Evidence of Impact

This section summarizes quantitative and qualitative outcomes associated with the CAPTURE Project and subsequent federally and state-funded initiatives led by Drs. Zilouchian and Romance. Evidence is organized around enrollment, persistence, academic preparation, and workforce alignment[27]-[30].

IV.1 Growth in STEM and Engineering Enrollment

Across the eight-year period examined, the combined initiatives contributed to sustained growth in STEM enrollment at multiple points along the pipeline. High school participants in CAPTURE-aligned activities demonstrated increased enrollment in dual-enrollment STEM courses, particularly in engineering technology, computer science, and cybersecurity pathways. At the community college level, articulation agreements supported smoother transitions into AS and AA STEM degrees with subsequent matriculation into the BS CS degree program, while university-level data showed increased enrollment in engineering, computing, and AI-related programs.

IV.2 Persistence and Retention Outcomes

Students who participated in multi-semester engagement activities—such as maker labs, engineering systems projects, and CyberCorps preparatory experiences—persisted at higher rates than peers with no structured pre-college exposure. Persistence gains were particularly notable among first-generation and Hispanic students, reinforcing findings from national studies on structured pathways and mentoring [9], [12].

IV.3Academic Readiness and Skill Development

Assessment of academic readiness focused on both cognitive and non-cognitive indicators. Participants demonstrated improved performance in mathematics-intensive gateway courses, stronger problem-solving confidence, and increased familiarity with engineering tools such as simulation platforms, coding environments, and systems modeling software. These outcomes align with discipline-based education research emphasizing active, applied learning [13], [20].

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IV.4 Impact of Scholarship and Financial Support Structure Two current grant projects have also increased STEM enrollment, retention and degree attainment. The NSF S-STEM scholarships program lead to student completion of a MS degree in Artificial Intelligence. Pursuant to the grant requirement, these students needed to be both high GPA and high financial need. Over the four-year S STEM grant period, only two students did not complete the program. Secondly, the current NSF CyberCorps®: Scholarship for Service grant initiative played a critical role in reducing financial barriers and enabling full-time study in Cybersecurity. Even with government shutdowns, the University was able to create cyber-related internships for the participating students who are now soon to graduate and are prepared and required to apply for two-year positions with a cyber-related government entity (e.g., FBI, Naval Air Warfare Research group). All enrollees have successfully reached this point, and a new cohort will be selected soon. Scholarship recipients exhibited higher completion rates and stronger engagement in undergraduate research, internships, and career readiness. An ongoing Sharing Success Seminar series engaged students on a weekly basis (during COVID) and then bi-monthly with stimulating topics, individual and/or student team presentations, and with guest speakers. Their on-going engagement with faculty monitoring impacted their communication and team-building skills. Increased opportunities that address critical retention and graduation factors (e.g., academic monitoring and support, financial aid, internships, and opportunities to build career readiness) as well as students' interpersonal skills (e.g., sense of belonging, motivation, self-efficacy) and intrapersonal competencies (e.g., communication, teamwork) combined with financial support serve as a operational framework ensuring student success in STEM degree completion.

IV.5 Post-Secondary Alignment with Workforce Development

Engagement with workforce development agencies, industry partners and community agencies strengthened both curricular relevance and student motivation. Employer participation in hackathons, cybersecurity simulations, and the *Engineer Your Future* event (i.e., a middle-high school full day on-campus STEM experience) reinforced connections between pre-college learning and real-world engineering careers. Community agencies (e.g., Boys & Girls Club, Urban League, the Children's Services Council) with encouragement and support from the US Department of Educations' Promise Neighborhoods grant to Florida Atlantic University were able to increase their emphasis on pre-collegiate STEM activities, thus providing many low SES students with opportunities to engage early and often in their K-12 education in STEM activities. Building partnerships with both individual companies (LexisNexis, Silver Logic, Pratt-Whitney) and regional business/economic hubs (e.g., South Floria Tech Hub, Tech Gateway, and Greater Fort Lauderdale Business Alliance) along with career-centric organizations (e.g., FAU's Career Center; Community College Career Centers, CareerSource) and the statewide HANDSHAKE network (i.e., now required for all students entering any public, post-secondary institution in Florida's university system), provided stimulating career learning opportunities for all students. These findings align with workforce projections emphasizing demand for computing, cybersecurity, and AI competencies [1], [5], [23].

V. STEM Ecosystem: Start Early

Throughout this paper, we have highlighted specific trends that clearly attest to need to start STEM education at a much earlier educational level, if, in fact, we are serious about building the world's best STEM workforce and the associated industries and national defense infrastructure. Reflecting for a moment on the NAEP scores, the lack of an adequate and highly prepared workforce, and the disengagement of a growing minority population in STEM pathways, our regional STEM ecosystem has a definite mandate to grow and expand the 'call to all' to build a robust STEM ecosystem as part of a sustained and community-wide effort. Members of the regional STEM ecosystem including strong leadership from the regional post-secondary institutions (e.g., FAU, PBSC, and BC) have made STEM a regional focus. The university and the state colleges in collaboration with two large, urban school districts (N=236,000 and N=160,000 students) have partnered with industry, non-profit community agencies and now, big corporate donors. Several examples are provided here to illustrate this growing STEM ecosystem. The recent US Department of Education (soon to the US Department of Labor) Promise Neighborhoods grant awarded to Florida Atlantic University features funding for Carnegie Learning to provide, continuing, high quality professional development for high school Algebra teachers to bolster student achievement outcomes in high school Algebra, a Florida requirement for graduation, while also working with the district curriculum staff to plan for increased enrollment of students in higher level math (e.g., Pre-calculus, Calc I) while still in high school. Grant funds are also allocated for professional development for elementary teachers including enhanced use of manipulatives to help students visualize math concepts. Programs like TRIO and Upward Bound at the University and Community Colleges connect with regional K-12 schools to provide on-going STEM enrichment for students. A major corporate donation has created the Stiles-Nicholson Brain Institute which features STEM-teacher professional development opportunities plus a traveling Mobile-Minds van which, when visiting K-12 schools, actively engages students in technology-enhanced opportunities to learn about the wonders of the human brain. Grant funds and corporate sponsorship have helped to create 'specialized' gardens on select K-12 school campuses. These are Technologically Enhanced Gardens (TeaGardens) (e.g., Broward TEA Garden Food Forest) and are designed to educate students, teachers and their communities on how and why they can sustainably grow edible food together in their neighborhoods. Integrating schoolyard edible gardening in classrooms, cafeterias and afterschool programs, the Broward TEA Garden Food Forest also incorporates exciting technology used in the agriculture industry, such as drones, sensors, artificial intelligence, and digital data collection and collaboration.

Students engage in real-world, culturally relevant STEM project-based learning opportunities to create environmentally sustainable solutions to environmental challenges utilizing a range of technological innovations to monitor gardens, cultivation, and harvesting in their school and communities. Table 6. shows enrollment, retention, or completion changes over time, especially for key demographic groups.

Table 5. Enrollment, Retention, and Completion Indicators Across STEM Pipeline Initiatives (2016–2026)

Initiative	Metric	Post-Implementation / Most Recent	Demographic Focus
CAPTURE Project	Institutional Enrollment Context	Please see the Tables and Graphs	BC: 35% Hispanic; PBSC: 27.5% Hispanic
	Financial Need Indicator	Continued participation of high-need populations (BC: 55%+ Pell-eligible; PBSC: 53% need-based aid eligible)	Low-income students
	Transfer & Persistence	CAPTURE-supported students persisted at higher rates than national benchmarks	Community college STEM students
	AA STEM Completion	Post-intervention AA STEM completion rates Please see the tables and graphs	AA STEM students
HSI Title III STEM Articulation (2016–2023)	Transfer	Please see the reported Data	Hispanic transfer students
	Gateway Course Outcomes	Improved pass rates in College Algebra, Calculus I, and Intro Programming (exact % TBA); Increased Title III student enrollment at the University	Hispanic & low-income STEM students
NSF S-STEM Scholarships	MS Completion Rate (AI Track)	128 Scholarships Awarded	High-GPA, high-financial-need students
	Research & Career Engagement	Increased research participation, increased completion of the MS in AI, improved graduate persistence	High financial need students
NSF Cyber-Corps® SFS	Retention to Graduation	5 Scholarships awarded to Cohort 1; 100 % progression toward graduation	Cybersecurity scholars
	Federal Workforce Placement Pipeline	100% Federal government workforce placement eligibility pathway	Cybersecurity workforce cohort

Initiative	Metric	Post-Implementation / Most Recent	Demographic Focus
Promise Neighborhoods STEM Ecosystem	Increased pass rate in high school Algebra	Increased pass rate on the required FL Statewide Assessment in Algebra Assessment enrollment in Pre-Calculus & Calculus I	Promise Neighborhoods Students in select zip codes in Broward County
	Middle School Math Cadets	TBA Increased number of high school students serving as mentors for struggling middle school math students	K–12 pipeline students
	K-5 Mathematics	TBA – Increased number of elementary students making satisfactory progress Florida's STAR Assessment	K-5 pipeline students

VI. Lessons Learned: Building Sustainable Pre-College to Engineering Pathways

Drawing on more than eight years of implementation across multiple externally funded initiatives—including CAPTURE, the Title III HSI STEM Articulation Project, NSF S-STEM, NSF CyberCorps®, and Promise Neighborhoods—this work yields a set of transferable lessons for institutions seeking to strengthen pre-college engineering pathways, particularly within urban and Hispanic-Serving Institution (HSI) contexts. These lessons are organized across structural, pedagogical, partnership, and equity dimensions.

Lesson 1: *Early Authentic Engineering Experiences Matter More Than Awareness Campaigns*

One of the most consistent findings across CAPTURE and subsequent initiatives was that sustained engagement in authentic engineering practices—rather than one-time outreach or awareness events—had the strongest influence on student persistence. Maker labs, engineering systems modeling, cybersecurity simulations, and AI-infused projects allowed high school students to *see themselves* as engineers before matriculation. This aligns with prior research on informal STEM learning environments and identity formation [11], [15].

Lesson 2: *Articulation Must Be Cultural as Well as Curricular*

While formal articulation agreements between high schools, state colleges, and the university were necessary, they were insufficient on their own. Faculty-to-faculty collaboration—joint curriculum design collaboration across post-secondary institutions, shared assessment rubrics, and co-mentoring of student projects—proved critical. The HSI STEM Articulation Project demonstrated that students were more likely to persist when curricular alignment was paired with consistent academic expectations and advising practices across institutions [9], [10].

Lesson 3: *Mentoring Structures Must Be Diagnostic and Tiered*

Across multiple programs, a hierarchical and diagnostic mentoring model was implemented, informed by Wilson et al. [25] and refined by Zilouchian and Romance [27]-[30]. Rather than assigning uniform mentoring supports, students were assessed across academic preparation, self-efficacy, financial stability, and family educational background. Supports were then tiered accordingly, combining peer mentors, faculty mentors, and industry professionals.

Lesson 4: *Faculty Engagement Is the Primary Scaling Mechanism*

A defining feature of the South Florida STEM Ecosystem was sustained faculty leadership. Faculty were not peripheral contributors but principal investigators, curriculum designers, and community ambassadors. This distributed leadership model enabled continuity across grants and reduced the common problem of initiative collapse after funding cycles ended. Engagement across ASEE divisions and professional societies further amplified dissemination.

Lesson 5: *Industry Partnerships Strengthen Relevance and Legitimacy*

Regional industry alliances played a dual role: informing curriculum relevance (especially in cybersecurity and AI) and legitimizing engineering pathways in the eyes of students and families. Industry-sponsored challenges, internships, and participation in events such as university-sponsored *Engineer Your Future* and industry-sponsored *Claim Your Future* provided tangible connections between pre-college learning and workforce outcomes, reinforcing national calls for workforce-aligned STEM education [1], [23].

Lesson 6*: Equity Requires Structural Investment, Not Add-On Programming*

The combined experiences of S-STEM scholarships, and Women in Computing partnerships reinforced that equity is achieved through structural investment—scholarships, advising capacity, paid research experiences—not through isolated diversity programming. First-generation and underrepresented students benefited most when financial, academic, and psychosocial supports were integrated into program design [12], [18].

Lesson 7: *Data-Informed Iteration Improves Program Effectiveness*

Continuous assessment using mixed methods—including enrollment trends, persistence data, and student surveys—enabled iterative refinement of activities. Regression discontinuity and quasi-experimental approaches, aligned with What Works Clearinghouse guidance [24], strengthened the evidence base and informed scaling decisions.

Collectively, these lessons suggest that sustainable pre-college engineering pipelines require long-term institutional commitment, cross-sector partnerships, and faculty-driven ecosystems. The CAPTURE model and its subsequent extensions demonstrate that HSIs are uniquely positioned to serve as regional hubs for equitable engineering education pathways.

VII. Challenges and Lessons Learned from Implementation Barriers

While the CAPTURE framework and the previously described federally funded initiatives demonstrate measurable progress in strengthening STEM pathways, their implementation revealed structural, institutional, and contextual barriers that significantly shaped program evolution. Understanding these challenges is critical for institutions seeking to replicate or scale integrated pre-college to university engineering ecosystems, particularly within Hispanic-Serving Institution (HSI) contexts.

VII.1. Institutional Differences Between Two-Year State Colleges and Four-Year Universities

One of the earliest and most significant challenges involved structural and administrative differences between two-year state colleges and a four-year research university. Governance models, credentialing requirements, compensation structures, academic policies, and operational procedures differed substantially between the institutions. Addressing these complexities required more than one year of sustained coordination and institutional negotiation.

High-level communication between Presidents and Provosts at the state colleges and the university was critical during the initial implementation phase. Executive-level alignment provided institutional legitimacy, reduced bureaucratic delays, and facilitated resolution of policy-level barriers. Without this top-level commitment, operational alignment at the departmental level would have been significantly delayed.

VII.2. Structural Transfer and Articulation Barriers

Although formal articulation agreements were established between the state colleges and the university, early implementation revealed that written agreements alone were insufficient to guarantee seamless progression. Variations in course sequencing, credit-hour allocations—particularly in mathematics prerequisites—and advising practices resulted in occasional delays in student advancement within mathematics-intensive engineering pathways.

Even minor discrepancies in prerequisite expectations accumulated over time and affected students' time-to-degree. Coordinating and advising across three institutions presented additional challenges. Weekly cross-institution advising meetings and sustained communication proved essential in resolving course equivalency issues and monitoring student progress.

***Lesson Learned*:** Articulation must be both curricular and operational. Continuous faculty-to-faculty collaboration, shared assessment standards, and structured academic planning meetings are necessary to sustain alignment. Transfer efficiency improves when articulation is treated as an ongoing governance process rather than a static agreement.

VII.3. Gateway Course Attrition and Academic Preparedness

Mathematics (College Algebra through Calculus I) and Introduction to Programming consistently emerged as high-risk gateway courses with historically elevated DFW rates. These bottlenecks disproportionately affected Hispanic, first-generation, and low-income students entering engineering and computing pathways.

Refining curriculum and integrating structured mentoring required substantial faculty coordination, transparency in DFW data reporting, and shared accountability across institutions. Resistance to modifying established course structures required deliberate engagement, trust-building, and iterative refinement based on performance data.

Lesson Learned**:** Gateway reform requires layered support structures. Course redesign alone is insufficient. Improvements were most effective when paired with diagnostic mentoring, peer-assisted learning, embedded tutoring, and explicit alignment with downstream engineering applications. Incremental, evidence-based refinement proved more sustainable than wholesale curricular replacement.

VII.4. Enrollment Volatility-COVID-19

The final two years of the HSI project coincided with unprecedented national enrollment disruptions. During 2020–2021, national transfer enrollment declined by approximately 191,500 students, and Hispanic-Serving Institutions experienced an 11.8% reduction in transfer students. Florida state colleges reported roughly 55,000 withdrawals in 2020. These macro-level disruptions threatened continuity in newly established STEM pathways and created significant uncertainty for students navigating transfer processes. Enrollment of state college students participating in the program declined substantially during this period.

Lesson Learned**:** Ecosystem resilience depends on integrated academic, financial, and psychosocial supports. Programs with embedded mentoring structures, online course delivery capacity, proactive advising outreach, and scholarship funding demonstrated greater stability during crisis conditions. Institutional flexibility and coordinated communication infrastructure were critical to sustaining student persistence.

VII.5. Financial Barriers and Competing Responsibilities

A substantial proportion of students served through CAPTURE, HSI and NSF S STEM initiatives were Pell-eligible or financially vulnerable. Many balanced employment and family responsibilities alongside rigorous STEM coursework. Financial instability consistently emerged as a strong predictor of attrition risk.

Lesson Learned**:** Equity requires structural investment. Scholarship programs such as NSF S-STEM and CyberCorps were central, not supplemental to student success. Financial support combined with academic monitoring, faculty engagement, and paid experiential learning opportunities significantly strengthened retention and degree progression.

VII.6. Faculty Workload, Compensation, and Credentialing Differences

Compensation structures and credentialing standards differed between state colleges and the university. Salary scales and incentive models were not aligned, and in some cases, state colleges were unable to provide competitive financial incentives for university faculty to teach at the two-year level. Conversely, many state college instructors were highly motivated to teach at the four-year institution but encountered differences in credentialing requirements and institutional policies.

Dr. Zilouchian worked closely with upper administration to address these disparities and to develop policies that enabled cross-institution instructional collaboration.

Sustained cross-institution collaboration required substantial faculty leadership. Faculty served as principal investigators, curriculum designers, mentors, evaluators, and community liaisons. Maintaining momentum across multiple grant cycles required ongoing institutional recognition and support.

***Lesson Learned*:** Distributed leadership and institutionalization are critical. Initiatives embedded within departmental planning processes—rather than dependent solely on external grant cycles—demonstrated greater sustainability. Faculty engagement functions as the primary scaling mechanism in ecosystem-based STEM reform.

VII.7. Data Integration and Evaluation Complexity

Developing a multi-institutional longitudinal data system required navigating FERPA constraints, incompatible reporting platforms, and complex inter-institutional data-sharing agreements. Early data integration efforts were resource-intensive and occasionally delayed comprehensive impact analysis.

Lesson Learned: Evaluation infrastructure must be designed concurrently with program implementation. Early engagement with institutional research offices and standardized cross-campus data definitions strengthens longitudinal analysis, supports rigorous assessment, and enhances dissemination credibility.

Collectively, the above challenges illustrate that strengthening STEM pathways within HSI contexts requires more than curricular reform or isolated programmatic interventions. The barriers encountered—ranging from institutional misalignment and gateway course attrition to financial instability, faculty workload disparities, and data integration complexity—were systemic rather than individual. Addressing them required sustained executive-level commitment, cross-institution faculty collaboration, structured financial investment, and the development of academic and advising infrastructures. Importantly, several of the most durable gains emerged during periods of national enrollment volatility, underscoring the stabilizing effect of an integrated ecosystem model. The experience demonstrates that scalable STEM pathway reform depends on long-term institutionalization, distributed leadership, and coordinated structural investment across educational sectors.

VIII. Conclusions

This paper presented a comprehensive, multi-year examination of a regional, faculty-led strategy to strengthen engineering and STEM education pipelines from high school through community college and into university and graduate-level programs. Grounded in the experiences and ASEE-disseminated work of Zilouchian and Romance [27]-[30], the initiatives described—including CAPTURE, the Title III HSI STEM Articulation Project, NSF S-STEM, NSF CyberCorps®, Promise Neighborhoods, and local, regional and national partnerships—demonstrate that sustainable engineering pathways require early engagement, intentional alignment, and long-term institutional commitment.

The findings presented reinforce several critical insights. First, STEM-Based and authentic engineering experiences in pre-college settings are essential for building student identity, confidence, and persistence. Second, continuity of expectations and support across educational transitions reduces attrition and strengthens equity outcomes, particularly for Hispanic and first-generation students. Third, faculty-driven ecosystems—supported by industry and informed by workforce needs—provide a scalable model for regional impact.

As national demand for engineering, AI, and cybersecurity talent continues to grow, institutions serving diverse populations must play a central role in developing inclusive, workforce-aligned pathways. The models and lessons presented in this paper offer transferable strategies for educators, administrators, and policymakers seeking to strengthen pre-college engineering education and ensure that the future STEM workforce reflects the diversity and talent of the nation.

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