WIP: From Isolated Interventions to Pathways Systems: Early Insights into Ecosystems of Support for Pathways to Engineering and Computing

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Abstract

This work-in-progress paper introduces a cross-sector partnership assembled to design and implement a virtual bridge model to facilitate the high-school-to-college transition. First-year students often face academic, social, and cultural challenges as they adjust to increased rigor, a faster pace, and more autonomy. In response, summer bridge programs have emerged to strengthen students' academic skills while also helping them acclimate to new environments. These programs have long shown promise as interventions that improve students' first-year GPAs, academic self-efficacy, metacognition, sense of belonging, and relationship-building skills. Recent studies have also explored how bridge programs shape students' expectations and motivations for engineering and computer science careers.

However, little research examines the role of concurrent or follow-up interventions beyond the bridge experience in contributing to students' ability to effectively integrate into their engineering college and broader university environment. Current research practices often emphasize discrete interventions implemented and are studied in isolation from the systems of interventions necessary to support scholars' transitions across the education-to-career continuum. These practices result in a lack of scholarship on the comprehensive approaches necessary to support students within and beyond the first year of college.

To explore this phenomenon, we employ a collective case study approach and draw on narrative inquiry to examine participants' experiences across cases. We examine how opportunity structures and supports inform students' identity trajectories in engineering and computer science. This work-in-progress identifies four patterns: (1) opportunity structures serve as bridges and sequences across contexts; (2) faculty and student success staff act as brokers to external experiential learning opportunities; (3) institutional policies shape students' horizons for action and agency; and (4) living and learning communities function as both informational and interpersonal opportunity structures. These early findings illustrate how external programs and institutional policies intersect to shape students' opportunity structures and early career paths in engineering and computing.

Introduction

Students in engineering and computer science face significant challenges in their first year as they encounter greater academic rigor while navigating new social and cultural environments. Less than half of college freshmen who declare Science, Technology, Engineering, or Math (STEM) majors are retained in their chosen fields to graduation [1]. While these transitional challenges potentially lead to early departure from STEM majors, Summer Bridge Programs (SBPs) have emerged as a noteworthy intervention strategy. SBPs provide incoming first-year students an opportunity to develop academic and cognitive skills prior to the start of their first semester [2]. By improving retention during the first year, a critical transition point, institutions implementing a bridge model can better support early-career engineering students and contribute to increased STEM degree completion.

Bridge programs have demonstrated promise as interventions that can improve students' first-year grade point average [3], academic self-efficacy [4], metacognition [5], sense of belonging [6], and relationship-building skills [7]. Decades of research further indicate that bridge programs are effective in retaining students in STEM majors through multiple contributing factors [2], [8]-[9]. Academically, these programs often prioritize math readiness, which is widely considered a gatekeeper to success in engineering and computer science [10]. Several programs include a preview of introductory Calculus with evidence of increased math placement scores and first-semester math grades as a result [11]-[12].

In addition to academic preparation, SBPs frequently support students' social transitions, particularly for marginalized populations who face a higher risk of attrition [7]. These programs enhance navigational capital, defined as "skills that help students maneuver through educational institutions with dominant cultural norms" [13, p. 97]. Navigational capital may be developed through interactions with college faculty [3], networking with industry partners, and establishing peer learning communities through mentorship. Programs that incorporate an 'Introduction to College' component have been shown to be one of the most beneficial aspects of a SBP, with students reporting an increased sense of preparedness for their coursework [7]. Similarly, one study found that participants identified mentorship through the SBP as the primary reason for their persistence in engineering [14]. More recent studies have begun to examine how bridge programs shape students' expectations and motivations for pursuing careers in engineering and computer science, with evidence suggesting a positive influence on college STEM career aspirations [15].

Despite these documented benefits, traditional quantitative metrics alone may be insufficient measures of the long-term success of bridge programs, as their effects may not directly correlate with student outcomes beyond the first year [6]. Prior research suggests that as students progress through their college careers, their needs evolve and the impact of SBP participation may diminish over time. Consequently, different or additional interventions may be required to support students beyond initial program participation [12]. This phenomenon warrants further exploration through approaches that attend to students' holistic experiences across their evolving trajectories.

Although evidence supports the short-term benefits of bridge programs, little is understood about the role of post-program support or follow-up interventions that contribute to the long-term outcomes and students' ability to effectively integrate into an engineering college and their broader university environment. Institutions provide varying levels of intervention and support, underscoring that there is no set formula for creating an effective program, making it difficult to draw conclusions about which aspects may lead to positive outcomes [9]. Furthermore, research emphasizes isolated interventional strategies, lacking scholarship on the comprehensive approaches necessary to support students within and beyond the first year of college. To address this phenomenon, this study employs a collective case study design integrated with narrative inquiry to examine how external and internal institutional structures and supports shape students' identity trajectories in engineering and computer science.

Theoretical Approach

Guided by an adapted framework of identity trajectory theory, this research project aims to understand the influence of both internal and external opportunity structures and how students actively navigate them to construct their identity trajectories. Identity trajectory theory assumes that professional identities are shaped by three interconnected strands: intellectual, institutional, and networking, along with other key constructs, such as agency, opportunity structures, and horizons for action [17]-[19]. Identity trajectory theory provides a dynamic lens for understanding how students construct and sustain their identities as future engineers and computer scientists.

In this study, institutional structures refer to the policies, rules, and practices that govern higher education [20]. Institutional support encompasses the resources and services specifically designed to assist students throughout their academic journey. Together, these elements contribute to students' opportunity structures, a set of pathways students perceive as possible for their education and career [21]. These opportunity structures are shaped by the presence of institutional structures and support, as well as the external programs that emerge to fill institutional gaps. For example, when institutions lack resources to offer summer bridge or math readiness programs, external interventions such as the National Virtual Bridge Program can expand students' opportunity structures by providing academic preparation, mentoring, and networks that would otherwise be unavailable.

Project Approach

Program Context

This study is situated within the context of the National Virtual Bridge Program (NVB), a 5-week summer bridge program designed for rising first-year undergraduate students in engineering and computer science. Unlike traditional residential bridge programs offered by higher education institutions, NVB is led by NACME, an educational nonprofit that serves as a critical partner to industry and higher education institutions. NACME aims to prepare undergraduate students for success in STEM through scholarships, skills-based training, and experiential learning.

This model integrates educational support, community building, career development, and academic coursework. More specifically, students participate in course previews focused on Pre-calculus, Calculus I, Physics I, Python, and Engineering Design, with opportunities to engage in recitation and tutoring sessions. Additional features include student success workshops offered by organizational partners, such as NAMEPA, university programming sessions led by their university representative, and professional development workshops offered through NACME's professional development webinar series. Within the engineering design course, students are introduced to MATLAB and can interact with industry professionals through NACME's partnership with MathWorks. To encourage participation and engagement, students who completed the bridge program received a $500 stipend.

Research Design

This project has received the necessary approval from the University of Kentucky's Institutional Review Board #108221 for conducting human subjects' research. This paper reports preliminary findings from a pilot phase of a larger multi-site study. The broader research project employs a collective case study design integrated with narrative inquiry to examine how external and internal institutional structures and supports shape students' identity trajectories in engineering and computer science. The collective case study design is employed to explore multiple cases that are connected by a similar issue [22]. In contrast, narrative inquiry focuses on the lived experiences of others through narratives or stories [23].

Purposive sampling was used to recruit first-year undergraduate students studying engineering and computer science who participated in the National Virtual Bridge Program [24]. Each institution will be treated as a distinct case, defined by its own context and structures. Within each case, the students' narratives will highlight how the external and internal opportunity structures are experienced at the individual level. The larger study aims to examine how these experiences interact with institutional contexts and structures to shape students' identity trajectories toward engineering and computer science careers, while this paper reports findings from a pilot phase conducted at two sites. The information gleaned from the pilot will inform the refinement of the interview protocol and early insights about the internal and external opportunity structures.

Data Collection

A recruitment email was sent to the list of former NVB scholars. This email described the purpose of the study, expectations for participation, and the interest survey. The interest survey allowed students to indicate their availability and current academic performance during the first semester of college.

For the pilot phase, we conducted 60-minute interviews with three scholars who successfully completed the National Virtual Bridge Program. Drawing on identity trajectory theory, we used a semi-structured interview protocol to facilitate one-on-one interviews. This protocol consists of background questions inquiring about the students' journey to pursuing a career in engineering or computer science, followed by questions about their curricular and co-curricular experiences, interactions with peers, faculty, staff, and professionals, and the institutional structures and resources that influence their identities as engineers. Students were also asked to reflect on how NVB and other post-program support influenced their transition, as well as the resources or support that were absent and could have improved their academic, social, and professional integration into college.

Self-reported academic performance from the interest survey was used to support follow-up probing related to critical incidents in which students may have needed to leverage internal or external academic and social support. Collectively, these questions were designed to enhance our understanding of the opportunity structures drawn upon to strengthen their career pathways in engineering and computer science.

Data Analysis

Using the transcript generated from Microsoft Teams, the research team reviewed each transcript for accuracy and applied pseudonyms to protect the anonymity of the research participants. First cycle coding combined deductive and inductive approaches [25] in Dedoose, a qualitative coding software. We applied an initial coding framework centered on internal and external opportunity structures. Additional codes were developed inductively to capture instances of agency, horizons of action, institutional and structural conditions shaping student pathways, areas of opportunity, key differences between types of support structures, and other contextual factors described by the students.

Over time, the internal and external opportunity structure codes were further refined into nested sub-codes that reflected the type of support described, including instructional, institutional, and interpersonal/networking opportunity structures, which were consistent with constructs observed in previous studies [20], [26]. Additional sub-codes include experiential and informational opportunity structures. During the second coding cycle, pattern coding was used to synthesize findings across participants, yielding four patterns. This paper will not include constructed narrative accounts to report the results of the preliminary analysis.

Key Findings

Each student described both internal and external support as key opportunity structures shaping their academic, social, and professional integration at Research 1 and Research 2 Carnegie Classified Public Institutions in the Southeast (University A) and Mideast (University B) Region of the United States. Together, these experiences begin to illustrate how opportunity structures can function as bridges and sequential pathways across contexts, faculty and student success staff serve as brokers for experiential learning opportunities, institutional policies can shape students' horizons for action and agentic behaviors, and living learning communities can act as information and relational anchors that influence the educational and career pathways of early-career engineering and computing students.

Opportunity structures function as bridges and sequences across contexts

This pattern highlights how students' education and career pathways are shaped through opportunity structures that span multiple settings and operate as bridges across contexts and sequences over time. Rather than describing these structures as isolated resources, students emphasized that engagement in one opportunity often enabled access to subsequent internal and external support, reinforcing the interconnected nature of the ecosystem. Most importantly, they emphasized that participation in NVB served as a gateway to subsequent student success programs, including a two-week residential program at University A and a year-long program at University B.

While students at both sites referenced the National Virtual Bridge Program as an external opportunity structure that supported college and career readiness, they often described its role as providing either early exposure or reinforcement of foundational concepts critical to the engineering and computing gateway. Students enrolled at University A often described how both internal and external programs contributed to early preparation and exposure to concepts in Calculus I, such as the unit circle, product, power, and chain rules, which are used for derivatives. For some students, including Breon, this support functioned primarily as a refresher rather than as an initial exposure to Calculus I concepts. In contrast, this exposure enabled other students, Saylor and Maci, to gain a "headstart on the first couple of assignments," and earn a good score on the first exam, priming them with an early win that helped build momentum in a core gateway course.

Similarly, the internal program provided direct support for their Introduction to Programming course. For example, the two-week residential program provided students at University A with the opportunity to learn MATLAB and apply those programming skills with Arduino Kits. This preparation strengthened students' confidence in their coding skills and positioned them to provide peer support in the credit-bearing programming course. Saylor shared how the internal program reinforced his prior knowledge and experience in programming from middle and high school:

> … The very first, like 5 weeks of [Introduction to Programming], I already had all the things done because we did it. … When my friends asked me, … how I already knew all the stuff, I was like ", I already did it," and they were like, are you serious? I was able to help out other people, and then we started getting into the more advanced stuff, I picked it up pretty quickly [be]cause I already knew I had a really strong foundation from the [two-week residential] program.

Maci shared a similar sentiment despite not having any prior coding experience beyond Python, offered by the National Virtual Bridge Program, and MATLAB, introduced through the internal, two-week residential program. Collectively, students described a pathway sequence in which NVB participation enabled entry into additional student success programs, which provided targeted preparation for gateway coursework and reinforced early academic momentum.

Faculty and Student Success Staff operating as brokers to external experiential learning opportunities

This pattern illustrates how multiple domains of opportunity structures, supported through interpersonal interactions with faculty, serve as pivotal entry points into external experiential learning opportunities. Students often describe faculty and student success staff as brokers who connected students to national internships and international research internships after observing their engagement and performance in academic and research contexts.

For example, one student described how a professor in an introductory programming course deepened his understanding of fundamental coding concepts and facilitated his connection to a summer internship opportunity at a government agency. Breon shared that the professor told students in the course that he could recommend one first-year student for an internship through his professional connection at a government agency. This announcement expanded Breon's horizon of action, which he internalized as a concrete opportunity to act upon. He shared how he intentionally prioritized the programming course to increase his chances of receiving the connection for the national internship, and these actions were reflected in his behavior, including active participation, seeking help during office hours, and offering peer support.

> … I had to make sure [I was] showing up early, going to office hours, [and] doing homework. Asking as many questions as possible and I think another important aspect was like helping people around me … So, [I] just made sure everyday to be as interactive in the class and helping other people. And I kind of caught his eye around like the second test [be]cause not everyone did as good on the second test as I did. So, I think that was kind of a defining moment and then after that [exam] my group did really good on the final project

> and then on our final assessment, I got a perfect score. So, I think that was kind of the nail in the coffin.

In another example, Maci described how she learned about research opportunities through tours of laboratories and centers during the two-week residential program. While she did not pursue an opportunity at the centers featured on the tour, she pursued other research experiences through an online tool called ForagerOne, which matches research faculty with undergraduate students. Once integrated into the university energy research center, her principal investigator encouraged her to apply for an international research internship through the university's energy research center. Together, these accounts suggest that instructional, experiential, and interpersonal opportunity structures function as gateways to experiential learning opportunities by linking students' early academic and research engagement and agentic behaviors to external opportunities that reinforce their educational and career pathways.

Institutional Policies Shape Students' Horizons for Action and Student Agency

This pattern highlights how institutional opportunity structures, such as policies, shape students' horizons for action by influencing what options are perceived as possible, visible, and leveraged when navigating academic barriers in gateway courses. One student described how he benefited from a program policy instituted by the College of Engineering's student success program that required at least 3 hours of studying in the tutoring lab per week, along with attending office hours and independent studying. This policy structured his agentic behaviors by reinforcing consistent help-seeking and sustained academic engagement while balancing a non-engineering co-curricular (e.g., marching band). Consequently, he excelled in his first semester of gateway courses, including Introduction to Engineering, Introduction to Programming, and Calculus II.

In contrast, students at University A described fewer institutional policies related to tutoring and reported no awareness of an institutional policy that could have enabled them to pivot into a lower-tier math course (e.g., pre-calculus). Without awareness of the late-switch policy, students perceived choices for navigating challenges in Calculus I were constrained, and both earned Cs in the course. Although both students referenced attending internal tutoring support programs, they also described difficulties with balancing academic and social responsibilities, including misrecognizing "free time" and reinforcing unproductive study habits that, as Maci noted, "came to bite" her later and were reflected in their final grade in Calculus I.

Living and Learning Communities Operate as Informational and Interpersonal Opportunity Structures

This pattern highlights how engineering living-learning communities can serve as key internal opportunity structures, providing informational and interpersonal anchors during students' transition to college. Students at University A often described their living and learning community as environments that provided built-in peer networks and mentorship, reinforcing studying and help-seeking behaviors for career readiness. For example, Maci shared how her peer mentor, a senior chemical engineering student, provided resume support and strategies for navigating engineering without consistent stress. The living and learning communities also serve as informational gateways to learn more about the career pathways of engineering professionals.

Discussion

In this pilot study, we examined how first-year engineering students leverage internal and external opportunity structures to support the academic and social transition to college. Across participants and institutional contexts, four key patterns emerged: 1) Opportunity structures function as bridges and sequences across contexts, 2) Faculty and student success staff operate as brokers to external experiential learning opportunities, 3) Institutional Policies Shape Students' Horizons for Action and Student Agency, and 4) Living and Learning Communities Operate as Informational and Interpersonal Opportunity Structures. Collectively, these patterns suggest that students' pathways are not attributed to a single, isolated source. Instead, these pathways are shaped by interconnected opportunity structures that function as bridges, brokers, and anchors across contexts, time, and domains.

Interpersonal opportunity structures, including relationships with faculty in academic and research settings, as well as peers and professionals in living learning communities, played a critical role in shaping students identity trajectories by expanding their horizons for action. For example, Breon and Maci described how faculty leveraged their professional networks to broker access to experiential learning opportunities. This finding builds on prior literature that categorizes faculty-student-interactions as either adversarial or supportive allies [27]. In that study, faculty operating as allies primarily influenced student pathways through informational support, such as course recommendations, instructional guidance, and advising on study abroad opportunities. In contrast, our findings suggest that faculty also function as brokers of experiential opportunity structures by actively connecting students to internships, international research experiences, and other professional experiences that exist beyond the classroom. This finding highlights how interpersonal relationships provide guidance while also serving as a mechanism that links students to broader ecosystems of support.

Institutional policies also shaped students' horizons for action by influencing how they engaged with available resources and developed a sense of agency. For example, Breon demonstrated the value of establishing policies that require students to actively use tutoring services, while Saylor and Maci revealed how access to tutoring centers alone is insufficient to support student success. These findings suggest that institutional policies function as structural conditions that either enable or constrain students' engagement with available supports [20]. Within an ecosystem of support, policies define access to resources and shape how and when students activate those resources as part of their broader academic and professional pathways.

This pilot study demonstrates the value of leveraging an ecosystem of support to sustain the benefits of summer bridge participation through continued access to post-program support. While an ecosystem approach to engineering and computing education has been positioned as a powerful lens for designing education and workforce pathways [28]-[29], existing applications of this lens are often situated primarily within higher education contexts [30] or offer no attention to the role of non-university affiliated organizations, such as NACME or its industry partners [29]. For example, [29] developed a "Pathways to Roadways" model depicting how individuals progress across education and workforce infrastructures, while [30] conceptualized student navigation within university embedded systems. While these models provide important insights, they offer less visibility into how external organizations contribute to students' academic preparation, social integration, and professional development. This study addresses this gap by illustrating how cross-sector partners function as integral components of students' ecosystems of support and extend access to academic, social, and professional opportunities beyond the university context.

Conclusion and Future Work

This study offers an ecosystem-informed pathway on engineering education that highlights how students navigate interconnected opportunity structures across diverse contexts. This approach recognizes the critical role of non-university affiliated organizations, including industry and non-profit partners, as active contributors to students' academic preparation, professional development, and access to experiential learning opportunities. As a pilot study, these findings provide an initial foundation for examining how programs, policies, and relationships across sectors can be more intentionally aligned to support students' transitions and trajectories. Future work will explore how this lens can be applied and refined across a broader network of university and non-university partners. By encouraging a shift from isolated program design to coordinated pathways, this work contributes to ongoing efforts to better align education, workforce preparation, and cross-sector partnerships in support of early career engineers and computer scientists [31].

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