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Engaging Government-Industry-University Partnerships to Further Gender Equity in STEM Workforce Education Through Technology and Information System Learning Tools

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ABSTRACT

This paper has two goals: First, to detail processes through which a project funded under a National Science Foundation workforce development program (Innovative Technology Experiences for Students and Teachers, ITEST) leveraged active partnerships among government agencies, industry firms, and universities to develop and study an innovative, out-of-school information system and technology workforce education program. The aim of the program was to improve equity of opportunity for high school girls. The program engaged young women from underrepresented subgroups in data science, analytics, information communication technology, and programming learning activities in an experiential, law enforcement computer forensics context. This description of the research team's process is intended as inspiration and guidance to others considering developing similar programs targeting workforce development in science and technical fields through an equity lens. Second, this paper shares reflections from senior project personnel on lessons learned while working with cross-sector collaborations, including challenges encountered while implementing components of the program facilitated by the partnership model. The authors adopt a reflective practice orientation, considering implications regarding the most useful—and evolving—roles that cross-sector partnerships might play in developing programs to help students traditionally underrepresented in technical fields be more aware of, interested in, and prepared for careers in science, technology, engineering, and mathematics (STEM) disciplines. In so doing, the authors offer insights about how university partners might address potential tensions involved in such collaborations.

Keywords: Gender equity, Industry partnerships, Analytics, STEM, Workforce development, Reflective practice

1. ABOUT THE PROJECT

Women in the United States are underrepresented in technology-focused professions (Keune et al., 2019). Barriers to equity include gender-related social influences (e.g., stereotypes, values, or prevailing role beliefs) and a lack of opportunities and support for girls navigating education pathways to such careers (Glass et al., 2013; Keune et al., 2019). Focusing on the latter to address inequities and diversify the technology workforce, a team of University of Central Oklahoma (UCO) researchers developed an out-of-school time (OST) program for high school girls, combining team-based learning activities, career explorations, mentoring, internships, and research fellowships. The resulting Computer Forensics (CF) Program is an authentic, experiential opportunity for young women to prepare for science, technology, engineering, and mathematics (STEM) and emerging STEM-related careers as diverse as CF Examiner, Data Scientist, Cybersecurity Specialist, and Artificial Intelligence Engineer (Billionniere & Rahman, 2020; Fitzgerald et al., 2014; Mew, 2020).

1.1 The NSF ITEST Program

To build an equitable, diverse workforce in STEM careers, the National Science Foundation (NSF) has identified ten priorities for investment in research and development (R&D) of innovations to grow human capital and sustain U.S. long-term competitiveness and global leadership (NSF, 2019). UCO's efforts focus on: (1) preparing learners for work at the human-technology frontier via innovation; (2) converging interdisciplinary research via partnerships; and (3) harnessing the data revolution via analytical tools (NSF, 2019). NSF awarded funding for R&D of UCO's learning innovation under their Innovative Technology Experiences for Students and Teachers (ITEST) program (award #1758975). NSF grants ITEST awards to study and improve innovations that enhance PreK-12 student outcomes crucial to emerging STEM-related career pathways. ITEST learning innovations are expected to apply "technology-rich experiences" to "increase interest in and awareness of STEM-related emerging careers" (NSF, 2017, p. 4). Importantly, NSF expects grantee investigators to leverage "business and industry partners" in their efforts to motivate students to pursue education pathways into STEM occupations. (NSF, 2017, pp. 4-5). This principle is grounded in the idea that partners from sectors likely to employ graduates in STEM careers are uniquely positioned to inform decisions about the technologies ITEST-designed innovations should include, as well as how they contribute to authentic, experiential learning for groups underrepresented in STEM.

In this article, we adopt a reflective practice lens to focus on and share retrospective lessons learned about this central tenet of the ITEST program. We also discuss translating assumptions about the value of partnerships into decisions about program design and implementation, with the aim of informing how senior personnel of similar education R&D projects might effectively engage diverse partners in their work.

1.2 The STEM CareerBuilder Project

The UCO team's project (2018-2022, including a COVID-related extension) pursued this aim in partnership with other entities, to design, implement, test, and improve the *STEM CareerBuilder* OST workforce and information systems (IS) education pathway for high school girls. The project team initially tested a one-week pilot version of the model in grant Year 1 (summer of 2018), which was based on UCO's previous *Crime Scene Investigation* (CSI) program. The Oklahoma State Regents for Higher Education funded CSI (2013-2018) to broaden STEM participation among underserved high school students, male and female. The new CF Program model included several substantive changes over CSI, the most fundamentally being its conception as an all-girl experience. This change was based on the finding from the CSI project that female students outperformed males in targeted STEM workforce-related outcomes in the Summer Academy model central to the program (Cheng & Feng, 2018). This decision proposed that increasing the number of girls given opportunities in STEM education programs most directly addresses the problem of gender underrepresentation, in turn increasing equity to grow a diverse, skilled, and innovative STEM workforce (National Research Council, 2002).

As implemented in what was intended to be its final form (grant Year 2, 2019), the program included a hybrid, two-week CF Summer Academy experience for 50 young women (an increase from 15 in the mixed-gender CSI program). The program combined in-person and online learning supported by selected K-12 teachers and student participants from previous years returning to serve as near-peer leaders. The model's core Academy activities were supplemented with additional opportunities—mentoring, internships, and research fellowship placements—available through competitive applications to five girls. The project team designed these activities to allow participants to interact with STEM professionals during Academy activities, then work with them one-on-one as a supervisor or mentor. Such independent activities were designed to complement experiential, team-focused learning facilitated by female role models for young women from industry and government (National Science Board, 2018).

1.2.1 Targeted Recruitment of Underserved Girls. Given the equity priority, the CF Program emphasizes targeted recruiting through venues chosen to reach girls generally, but more importantly to engage subgroups of females particularly underrepresented in STEM workforce pipelines. Recruiting outreach actively shared the CF Program opportunity with girls where they were already congregated, targeting those who would be first-generation college attendees, are from Native American communities for whom English is a second language, and/or who have a disability (Borgman et al., 2008; Dasgupta & Stout, 2014; National Science Board, 2018).

For example, 2019 Summer Academy recruiting provided program information to thousands of K-12 attendees of the Oklahoma Women in Science Conference, an activity of the NSF-funded Established Program to Stimulate Competitive Research (EPSCoR) program. Messaging was developed to reach girls supported by Oklahoma Promise, a state program to help children in low-income families with college scholarships, participating in federal programs for learners from economically-disadvantaged backgrounds (e.g., Female Upward Bound), attending the Francis Tuttle Technology Center (a vocational cooperative among four Oklahoma City school districts), and enrolled in the Metro Technology Centers' career and technology education system. The project team recruited participants from indigenous populations through Native American-serving institutions associated with the Choctaw Nation, the 11,000 square-mile tribal area in southeastern Oklahoma. Lastly, the primary investigator (PI) distributed program information through counselors positioned to reach underserved female students in more than 400 Oklahoma high schools.

1.2.2 Computer Forensics as an Emerging Interdisciplinary Field. CF is an emerging, interdisciplinary subfield of forensics that applies technology tools and analytic methods to gather and preserve evidence from compromised networks or computers (U.S. Department of Defense United States Cyber Command, 2015). With the cost of cybercrime anticipated to double between 2015 and 2021 to an estimated $6 trillion, CF has become increasingly crucial in fighting these contemporary crimes including cyber security breaches, terrorism, and various white-collar offenses (Morgan, 2019). The CF Program is a response to a growing need for CF professionals, resulting from increased reliance on technology and recognition of the costs and difficulty of dealing with cybercrimes (Choo, 2008; U.S. Department of Defense United States Cyber Command, 2015). While these labor needs are important, however, the CF Program uses forensics primarily as a lens through which girls examine STEM discipline content more broadly, and as thematic context for the outcomes that really matter—generalizable STEM, IS, as well as information and communication technology (ICT) skills and understandings.

1.2.3 Integration of IS Skills. The skills and knowledge required to effectively use IS tools, first within and then beyond the context of forensic investigations, make up many of the CF Program's outcomes. Participants learn them in a way that integrates IS fully with the other STEM- and workforce-related outcomes anticipated for participants—applying their growing IS skillset to learn other content, even as learning the content (e.g., analytic thinking or communication) serves as the vehicle to increase IS proficiencies. Program activities further this approach through collaborative career and skill-building explorations utilizing common workplace technologies across three IS realms—databases, programming, and analytics—in fully integrated ways.

1.2.4 Leveraging Multiple ICT Modalities for Content Delivery. From its inception as CSI, the program design has utilized web-enabled facilitation of learning activities, furthering ITEST R&D priorities by iterating the CF Program design each year in terms of delivery formats. The team's 2018 pilot of the central, weeklong portion of the Academy had girls participating onsite at the UCO campus. In 2019, the Academy was expanded to two weeks utilizing the hybrid model, with the first reprising the resident camp model at UCO and the second facilitated through a web-based learning management system. The model evolved further for 2020, transitioning the Academy to 100% online delivery in response to the COVID-19 pandemic. In hindsight, it was fortuitous that the intentional evolution of ICT modalities for the program laid the foundation for a fully online evolution of the model, the project team retaining this COVID-safe version of the Academy for the summer of 2021.

2. ENGAGING PARTNERSHIPS

Central to the STEM CareerBuilder project is the Government-Industry-University (GIU) partnership model—a purposeful, cross-sector collaboration of entities engaged in the R&D and learning aims of the project. The GIU partnership contributes to the delivery of the programming, but more importantly undergirds project R&D efforts, providing a collaborative framework within which K-12 educators, interdisciplinary college faculty members, STEM researchers, technologists, and industry professionals inform testing and improvement of the CF Program's career-exploration and skill-building curriculum.

As the name implies, the GIU approach brings together partner organizations from federal, state, and local governments (G), technology industries (I), and entities in the university system in Oklahoma (U). The government piece is largely law enforcement agencies given the forensics focus. Given existing organizational connections to transition high-school learners to post-secondary experiences, the final category also includes K-12 education partners and institutions serving Native American learners. The three-pronged partnership structure of the model itself was central to STEM CareerBuilder implementation, so it is only natural to extend it to broader thinking about partnering for education R&D efforts. It may be of further use, however, to guide consideration of the existing body of research on partnerships to support STEM education and workforce pipelines, the bulk of which focuses more narrowly on partnerships between universities and school districts (e.g., Bowen & Shume, 2020; Burrows, 2015; Cress et al., 2020; Hunter & Botchwey, 2016; Icel & Davis, 2018; Ufnar & Shepherd, 2019). This leaves gaps about how to best engage government and technology industry actors.

Synergies among these partner organizations helped create the precursor CSI program, with new representatives from all three sectors joining in the transition to the CF program. Under ITEST funding, contributions of GIU partners take several forms, including: (1) as key personnel managing the project, including development of curriculum and digital resources; (2) by serving on a cross-partnership advisory board, overseeing and guiding the work; (3) as Academy presenters, sharing their expertise and serving as role models; (4) as Internship Sponsors who select, supervise, and evaluate girls for positions as interns; and (5) as Fellowship Mentors, assisting selected girls with proposals and research projects of their own design.

The STEM CareerBuilder project's partnering approach bears certain similarities to—and notable differences from—other programs in the STEM workforce development space. Like programs in Kentucky (Strode et al., 2021) and western Michigan (Thelenwood et al., 2020), the STEM CareerBuilder project and CF Academy include partnerships with university, industry, and K-12 entities. However, the project and the CF Program are distinct in their specific focus on redressing inequities around gender, race, and class, objectives not thoroughly addressed in the academic and trade literature.

A formal, *a priori* process of collecting and analyzing evidence was adopted to answer the project's research questions, focusing on how partnerships with industry professionals and government entities encourage young women's awareness of and interest in STEM careers. In contrast, the inquiry central to this article, examining how better to engage those partners, applies a *reflective practice orientation*. The motivation for adopting this approach lies largely in response to challenges perceived by senior project personnel during the latter years of the project, regarding unexpectedly low rates of participants pursuing internships and fellowships. This effort aims to formalize a backward look at what worked—and what might have worked better—to maximize the value of partners' contributions over the life of the STEM CareerBuilder project, and to leverage partner relationships into increased internship and fellowship opportunities for CF Academy participants.

Reflective practice is the process of intentionally reflecting on professional experiences and decisions to grow one's expertise and develop one's professional practice. It is a practice, meaning it takes shape in action and in context, assuming significance and gravity as it moves the individual to deeper understanding and facilitates participation in professional communities of practice, where the ability and willingness to account for decisions are marks of membership. Educational philosopher John Dewey is widely credited as an early proponent of reflective thinking, emphasizing the generative possibilities of "perplexity, hesitation, [and] doubt" (1910, p. 9) as states of mind that help circumvent rote thinking and action. Dewey's ideas were taken up by Donald Schön (1983), who distinguishes between *reflection-in-action*, or thinking while doing, and *reflection-on-action*, or thinking after the event, to inform future practice. In this instance, the practice is retrospective reflection after the event, activated by the authors' *knowing-in-action* (or tacit knowledge), gained through expertise from years of collective experience.

Atkins and Murphy (1993) posit three stages of reflection: (1) *uncomfortable thoughts* or an awareness that things are not all well, what Schön (1983) refers to as the "experience of surprise" or what Boyd and Fales (1983) call a sense of "unfinished business;" (2) a *critical analysis* of one's own feelings and what is known about the situation; and (3) reflection with the intent of developing new perspectives on the question at hand. This article aims to serve that last purpose, ideally contributing something new to collective knowledge (*intellectual merit*, to the NSF, 2017) of how best to leverage GIU partnerships to develop, study, and implement education programs to address STEM workforce learning and participation outcomes.

2.1 Government Partners

Law enforcement agencies play a substantial role in the CF Program model, as forensic sciences serve as the thematic framework for young women's workforce learning activities. The Federal Bureau of Investigation (FBI) and Oklahoma State Bureau of Investigation (OSBI) have been key partners since UCO's inception of this approach. A Senior Criminalist from the Combined DNA Index System (CODIS) lab at OSBI was a crucial contributor to the program design, grounded in her professional expertise and six years of CSI program experience prior to creation of the CF Program. She is the key connection between the R&D team and OSBI, serving in a senior management role and supporting program operations (e.g., providing OSBI tours and coordinating lab materials for hands-on activities during the onsite Academy). Another senior OSBI staffer, an expert in digital evidence and cyber security, served on the project advisory board. OSBI also supports internships for girls interested in law enforcement or forensic sciences.

The Edmond (Oklahoma) Police Department (PD) provided substantial input on program activities, as well as (pre-COVID-19) site visits for participants. Their face-to-face contributions transitioned in the summer of 2020 to video explanations of digital forensics by a female presenter from the Edmond PD.

The Oklahoma City Office of Sustainability—responsible for technical assistance, planning, and outreach services to city departments and the public—partners by supporting internships, while representatives from the Oklahoma Center for the Advancement of Science and Technology (OCAST) have contributed in advisory roles and provided matching funds for internships with Oklahoma-based companies.

2.2 Industry Partners

As key IS industry players, Apple and IBM are the two most recognizable industry-sector CF Program partners. An Apple executive shared resources and advice with the project team to inform recruiting efforts and contributed as an Academy presenter. A Chief Technology Officer in IBM's Security Systems Division informed program development and facilitated girls' forensic analytics and cyber security learning activities.

Woman owners of Oklahoma small businesses also partnered with the project team in design and implementation of the CF Program. The President of Becks Intelligence Group, a longtime contributor (eight years, including with the CSI program), served in a senior personnel role and as a board member. Another female-identified technology-sector leader, with the nonprofit Oklahoma Women in Technology, presented at the Academy and managed internships.

2.3 University Partners

Educational institutions played crucial roles in project activities, as UCO led the NSF ITEST proposal. The PI and Co-PI (the latter Chair of the Computer Sciences department) managed development and implementation of the CF model, with support from technologists at the UCO Center for eLearning and Connected Environment (CeCE). Accustomed to helping university faculty design online coursework, the CeCE team developed human-computer simulations for the program based on real-world crime scenarios. The CeCE Director also provided expertise in STEM curriculum design as a board member. The UCO Center for Transformative Learning was a partner as well, helping develop active learning resources for the CF Program, and their director was also a board member.

Non-UCO postsecondary partners contributed as well, including the National Forensic Science Technology Center (NFSTC), an extension of the American Society of Crime Laboratory Directors situated at Florida International University. NFSTC provided the online introductory course in crime scene investigation that makes up the second week of the Academy. Given the emphasis of CF Program fellowships on research, university partner faculty played key roles as mentors to support girls' self-designed studies (e.g., a chemistry professor at Cameron University in Lawton, Oklahoma, mentoring a participant's nanotechnology project). And again, partners in this sector include education agencies in the K-12 pipeline feeding university programs, including the districts employing classroom teachers who facilitated the Academy and one who served in an advisory board role.

3. GIU PARTNER INFLUENCES ON THE CF MODEL

Partner institutions contributed to the CF Program in two ways: (1) by informing development of the model, and (2) by providing staffing support during its implementation to test and improve the program's curriculum, strategies, and interventions. Again, developers grounded the model's design on evidence that IS tools can support multiple aims in realizing those outcomes. Experiences that apply IS tools to authentic tasks aim to grow skills with these technologies while advancing outcomes in STEM content understandings and "soft skills" valued by employers (e.g., problem-solving). This premise reflects a key proposition of ITEST's theory of action, that innovative uses of ICTs encourage participation, engagement, satisfaction, and persistence in STEM career learning. Immediate outcomes should in turn advance skills and dispositions that ultimately lead to desired behaviors like increased STEM course enrollment (NSF, 2017).

The STEM CareerBuilder project research agenda explores relationships among education program features—particularly IS components—and this range of outcomes (McCreedy & Dierking, 2013; National Research Council, 2012; Reider et al., 2016). This theory-based approach influenced decisions about which technologies the CF model should employ, and how to integrate them into Academy learning experiences. Active participation of GIU partner staff in CF Program delivery helped assure that girls' learning authentically reproduces the world of work, and that they benefit from the examples and expertise of a diverse group of professionals. Other theories further argue that targeted competencies are transferable across disciplinary domains (e.g., Dede et al., 2005). The UCO team's schema categorized technologies by the purposes they support for the program's criminal investigation-driven learning activities. The contributions of various GIU partners can be defined within the same three domain areas: (1) Databases, (2) Programming and Analytics, and (3) ICT.

3.1 Databases

In the context of the CF Program, "database" outcomes include IS understandings relating to systematic thinking about data, variables and variable types, relationships among data elements, and concepts regarding storage and retrieval of data.

Law enforcement agencies regularly use collections of data in their investigative work, notably CODIS, the FBI's overarching program that supports the use of DNA databases in criminal justice, the National DNA Index System database of DNA profiles, and the Automated Fingerprint Identification System (AFIS), which serves functions and purposes similar to CODIS but for digital captures of hybrid, biometric (fingerprint) data. Since high school girls in an OST STEM learning program cannot be granted access to compare crime scene samples to profiles in live, law-enforcement databases, OSBI helped the project team develop online simulations that mimic them. OSBI forensic scientists introduced Academy participants to CODIS and AFIS, and university IS professors helped them understand how relational databases work, conceptually, and how to comb different types of data for analysis.

Some girls also applied their newfound understandings of data and data analysis to learner-designed optional experiences. For example, one high school student undertook an internship with the Oklahoma City Department of Sustainability to examine city-level greenhouse gas emission inventories of peer cities like Indianapolis and Salt Lake City, to make policy recommendations about the inventories and standards they could use moving forward. This example illustrates how the CF Academy cultivated conceptual understandings about data structures and computational reasoning that participants later had the opportunity to apply within new content areas.

3.2 Programming and Analytics

This grouping of IS uses in the CF model addresses *programming*, that is, the process of giving computers instructions allowing communications between humans and digital hardware, and *analytics*, the process of discerning patterns and making sense of raw data. Programming and data analytics are complementary skill sets; gains in one area advance learning in the other (Mortenson et al., 2015).

The CF Academy uses simulations to advance understandings in both areas. The Fingerprint Scanner, created by CeCE with input from OSBI, is a gamified learning tool that facilitates comparison of fingerprints from virtual crime scenes with examples from a simulated known perpetrator database. Another simulation teaches girls about Blockchain—a decentralized public record system that ensures integrity in data transactions—as they play the role of crime scene investigator, securely sharing evidentiary data from field investigations with a detective and forensic artist, documenting the chain of custody to ensure admissibility of evidence.

In addition to simulations, the CF Academy offers explicit instruction in programming and data analytics. A female Apple executive supported the development of an instructional module that teaches coding mobile apps using the Swift compiled programming language for iOS devices. Leveraging Apple's *Everyone Can Code* initiative, this activity promotes creative and systematic thinking to "bring ideas to life" that addresses real-world problems (Apple, Inc., 2021). Former FBI and OSBI agents spoke about analytics in investigative uses of DNA and cyber security, and a representative from IBM shared how the IT industry detects cybercriminal intrusions and network security breaches through behavior pattern analysis. IS experts demonstrated programming languages including Java, C#, and Python, and helped girls explore how Structured Query Language (SQL) can be used to create, read, update, and delete information in a database. Girls added these programming skills to their growing understanding about databases to work a fictional murder case, searching databases for fingerprint and DNA matches from their simulated crime scene.

Analytics and programming feature in internships and mentoring opportunities as well, such as in a data mining project with OSBI examining correlations between juvenile crimes and drug use. This work of a 2019 research fellow culminated in a presentation at a conference of the American Academy of Forensic Sciences. Another CF Program participant collaborated with a Fulbright Scholar in Iran, offering high school girls in her community free classes to learn Python for data analytics.

3.3 Information and Communication Technology

Finally, the CF Program cultivates familiarity and comfort with ICT systems of telecommunications and computing hardware and software for the creation, storage, and sharing of information. GIU partners made crucial contributions to designing how girls would use ICT tools to access resources and content, communicate with teammates, manage their forensic examinations, share information, and develop products of their investigations. Early iterations of Academy programming relied on live presentations to girls with participation in onsite presentations and hands-on processing of a staged crime scene.

For the 2019 Academy, a returning teacher helped develop online materials for these crime scene investigations, beginning the evolution from in-person to ICT-enabled experiences, which ultimately became necessary for program COVID-safe delivery in 2020. These enhanced resources were integrated into Academy activities alongside additional CeCE simulations designed to develop workplace skills like communication, collaboration, and critical thinking. Participants role-play 911 calls to a security specialist in the simulated *911 Triage and Information Center*, applying protocols developed by the Edmond Police Department. A *Crime Scene Investigation* simulation was introduced at the 2019 Academy, enabling OSBI agents and facilitators to guide girls to process a crime scene and collect digital evidence following authentic protocols in an immersive, virtual reality experience. Finally, the *Virtual Detective Office* provides interview rooms in which girls apply communication strategies designed by state and local law enforcement partners, with near-peer or professional Academy participants playing witnesses and suspects as avatars in a web-based environment. The GIU design team created these simulated forensic environments through which learners develop critical thinking by solving problems in authentic contexts using professional practices (Manlow et al., 2010; National Research Council, 2012).

The CF Program also leveraged a full slate of ICT tools to manage course delivery and communication outside of these virtual environments. Participants used other cloud-based ICT solutions to manage their activities—online meeting applications, a mobile texting app piloted in the 2018 iteration of the model, and networking tools like LinkedIn and Twitter. All of these were in environments resembling the virtual teams increasingly prevalent in networked, global workplaces, and technology-rich societies (Borgman et al., 2008; Reider et al., 2016).

4. LEVERAGING PARTNERSHIPS FOR LEARNING INNOVATION R&D

In considering the implications of engaging partners in efforts like the STEM CareerBuilder R&D project, the UCO team acknowledges that there is still much to be learned. Lessons come slowly when learning innovation development happens on 12-month implementation-and-improvement cycles. Further, successful partnerships are extremely difficult to achieve in practice, and research-informed understandings of how to establish productive working relationships across different types of organizations lag behind the substantial enthusiasm for these efforts (Noam & Rosenbaum Tillinger, 2004). It is also important to remember—and probably self-evident in the midst of the COVID-19 pandemic—that external factors impact program design and implementation decisions, separate from purposeful changes that research findings might recommend. While understandings about the role and influences of the GIU model continue to evolve, the project team has clarified several potentially useful ideas about leveraging cross-sector partnerships to better deliver technology-facilitated workforce education innovations.

4.1 Partnerships Are Powered by Individuals

Regardless of the GIU sector, connections between R&D project managers and partner agencies exist only through individuals affiliated with both the partner and the developmental research project. Individuals get involved in such projects for a variety of reasons, and motivations may change, as may contributors' professional positions and obligations. Teams delivering, studying, and improving education innovations therefore often experience turnover for reasons outside of project managers' control, leading to a loss of valuable connections.

Motivations frequently differ by partner type, presenting *orientation-related barriers* (Bruneel et al., 2010) to productive partnership. A university faculty member may have a different sense of urgency than an industry partner representative, depending upon the relationship of a project to the former's research agenda. Institutions may have policies or incentive systems that constrain or compromise partnering, for instance around intellectual property (IP) rights, an example of so-called *transaction-related barriers* (Bruneel et al., 2010). Individuals representing partners may also be more or less engaged, effective, or persistent depending on factors internal to a project like STEM CareerBuilder. It contributes to the effort, the specific roles to which they are assigned, the effectiveness of management processes (e.g., communication), and the extent to which individuals' contributions are valued or perceived as useful. Project managers must attend to such factors bearing on individual contributors' involvement, fixing those they can influence (e.g., task-tracking and teamwork practices) and accommodating or mitigating those they cannot. Barriers can be alleviated by prior collaborative research experiences and greater levels of trust (Bruneel et al., 2010), both of which develop at a person-to-person level as well as at an institutional or organizational level.

The development of trust takes time, and requires structures that facilitate individuals from partnering organizations to interact in ways that develop senses of mutual understanding and support; this requires in turn the dedication of personnel time to facilitate these structures and interactions (Noam & Rosenbaum Tillinger, 2004) in addition to the time and effort required up front to build and maintain relationships with area employers, schools, and community organizations (Thelenwood et al., 2020). Indeed, relationships are foundational to the development of deep and effective partnerships, and ideally should be cultivated even prior to the identification of funding opportunities (Allen et al., 2020; Ivey, 2019). This allows partnering organizations to articulate common goals and develop processes for working together on their own terms, exclusive of the influence of funders' requirements, an approach that is associated with highly sustainable partnership models.

4.2 Different Partners Make Different Contributions

During planning for the NSF ITEST proposal, the PI actively engaged partners from all three GIU sectors, assuring that design of the CF Program model represented their varying perspectives, and that all sectors would contribute to implementation of grant-funded R&D activities. This approach acknowledged that each partner entity brought to the project (through their representatives) specific expertise, technical capacities, connections, and other organizational capital important to the effort. Initially, individuals from all three sectors contributed in all the ways discussed previously—as senior personnel; in advisory positions; presenting or facilitating activities for participants; and sponsoring or supervising internships or fellowships. This calls to mind the *triple helix* model of innovation, in which R&D efforts among the three types of entities benefit from collaboration through interactive and nonlinear processes, versus a model in which universities "invent" through basic research and industry partners "apply" what is learned (Etzkowitz & Leydesdorff, 1995).

The sectors contributed in different ways and amounts across those functions, based on their interests in the CF Program and the grant-funded project studying and improving it. Government partners, largely law enforcement agencies, were instrumental in defining the substance of the forensics content, a very different role for government than that is typical in triple helix approaches where government entities are more likely to fund or facilitate R&D (Etzkowitz & Leydesdorff, 1995) or establish rules for IP ownership.

Industry partners' contributions were arguably different from those in traditional technology-transfer R&D partnerships. They made crucial substantive contributions to decisions about what workforce outcomes really matter, how high school students might learn them, and which technologies girls should learn to prepare for STEM education and workforce pipelines. Individuals from this sector also served as indispensable role models of women reaching leadership positions in technology and IS careers. Given the aims of ITEST and the UCO project, and the absence of any immediate return-on-investment, their institutional incentives and personal motivations for such contributions seem to be driven by social mission, or perhaps by abstract future benefits anticipated to accrue from productive STEM workforce pipelines.

University partners were central to developing the curriculum, materials, and technologies to facilitate both in-person and remote learning activities and played an important role in securing research-focused internship and fellowship opportunities for participants; while affiliated K-12 sector partners designed and executed efforts to recruit young women from underrepresented populations. As in Thelenwood and colleagues' (2020) discussion of a similar university-industry-community partnership model in the engineering space, the university partners focused on providing STEM content-heavy programming as opposed to sharing information about the university. While formal partnerships involving K-12 schools and districts and outside partners are typically fragile and challenging to sustain (National Research Council, 2012), the up-front recruitment role in which K-12 partners functioned in this instance made the partnership less vulnerable to changes in policy, personnel, or direction at the school or district level.

4.3 Needs for Partners Change Over Time

Given the relative areas of strength across the GIU sectors, ongoing evolution of the CF Program—as the product of an R&D effort—requires different contributions from different partners at various moments in its development. This happened for the STEM CareerBuilder team as their model matured and will likely be so for similar developmental research projects. Awareness of this dynamic, however, should be balanced against a simultaneous understanding of the importance of engaging continually with the same partners over long periods of time (Thelenwood et al., 2020). Encouraging contributors to define the substance of learning activities was crucial in the early phases of program development but became less so as content foundations for learning activities were laid. Conversely, industry partners became increasingly important as program participants transitioned out of facilitated group activities to individual, self-guided experiences requiring one-on-one mentors or supervisors. University partners may become less important if and when an innovation grows beyond being the subject of research and becomes commercialized, sustained, or scaled up by other means.

Different aspects of an educational innovation mature at different rates, or are best developed in a particular sequence, as was the case for Academy activities translated to ICT-enhanced (eventually fully online) modalities. Content must be defined before curricula are created, which must be prototyped before technologies can be fine-tuned for use with learners. Researchers must collect and analyze data about an innovation's utilization and outcomes before developers can make design improvement decisions.

Given that each partner brings unique expertise and other forms of capital to developmental research projects, their contributions might be greater or lesser depending on where the innovation is in the R&D cycle, from a new idea to an established model with demonstrated efficacy. The STEM CareerBuilder team experienced shifts in needs—and so in partnerships—as it engaged educators and technology workforce employers to develop IS-intensive programming to train future STEM professionals (Hoanca & Craig, 2019, p. 238). It accommodated these changes rather than actively planning for them, where (with hindsight) it should be possible to anticipate such situations. This is critical because workforce skills like innovation are crucial in global, digital markets, and STEM fields are at the core of our country's ability to sustain long-term competitiveness (Fifolt & Searby, 2010). Research and development of new models to effectively address these needs call for inclusion of a diverse set of partners as well as attention to nurturing individual relationships to optimize contributions. Attending to partnership structures as well as relationships is necessary to best evolve innovations and meet ever-changing project needs.

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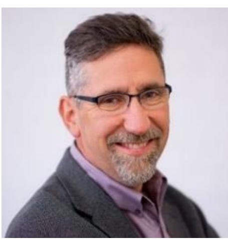

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