

A Comparative Study of AI-Powered Workforce Development via Forensic Analytics, Blockchain, and Metaverse

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This paper focuses on the outcomes of a Computer Forensics Summer Academy for High School Girls which was funded by the National Science Foundation over the 2018-2022 period. To overcome Covid-19 constraints, the project team adopted multiple content-delivery methods (in-person, hybrid, and virtual) to provide participants with career-exploration, job-shadowing, and professional-mentoring opportunities via information communication technology. Participants used artificial intelligence, blockchain, machine learning, metaverse, simulation, and virtual reality to analyze forensic data and solve simulations of modern-day crimes. Year-to-year comparisons revealed significant pre/post increases in participants' career awareness, forensic knowledge, and technical competencies with the exceptions of career interests and motivation. These unanticipated results contribute new knowledge to the NSF's comprehensive workforce model by examining how girls learn, work, and solve problems in varying multi-modality environments. As the learning space and workplace of the future evolve around human-computer technologies, insights on how to encourage STEM learning and workforce participation by under-represented populations become critical to better prepare today's digital learners and build an equitable and innovative workforce via collaborative partnerships, career-exploration opportunities, and skill-acquisition venues.

Keywords: forensic analytics, partnership, disruptive technologies, technical competency, innovation

INTRODUCTION

The University of Central Oklahoma (UCO) contracted research firm Inciter (Washington, DC) for a Design and Development Research (DDR) study to inform development of UCO's summer Computer Forensics learning experience for high school girls, and to assess preliminary evidence of efficacy of the model. Research was funded as part of UCO's National Science Foundation (NSF) Innovative Technology Experiences for Students and Teachers (ITEST) grant, entitled *A Government-University-Industry Partnership and STEM CareerBuilder for the R&D of an Innovative Computer Forensics Program and an Education-Career Pathway for Girls*, Award #1758975; Dr. Joselina Cheng, Principal Investigator (PI).

Background

NSF funded the project to implement, test, and improve the PI's *STEM CareerBuilder* workforce and information systems (IS) education pathway, created to address a growing need for Computer Forensics (CF) professionals in the United States by implementing strategies to improve inclusion of girls and women in the Science, Technology, Engineering, and Mathematics (STEM) workforce pathway—particularly toward forensic- and IS-related careers. Central to the STEM CareerBuilder model is the annual *CF for Girls Summer Academy* (“CF4Girls Academy” hereafter), a team-based, experiential, out-of-school time (OST) program. Originally, the project team designed this NSF-funded learning model to build upon a Criminal Justice summer program for high school boys and girls, developed with support from the Oklahoma State Regents for Higher Education (2014-2018). The same project team extended the NSF-funded CF4Girls Academy to include follow-up, student-guided independent career explorations including job shadowing, mentoring, internships, and research fellowships (described as separate “interventions” within the whole STEM CareerBuilder model). The CF4Girls Academy was a 2-week experience, blending virtual and in-person learning activities to maximize the relative strengths of each delivery mode. Learning activities are thematically aligned in a program that engages participants as members of a team of forensic scientists investigating a murder.

This package of skill-building and career-exploration exercises aimed to grow participants' attitudes, understandings, and abilities in using disruptive technologies to solve modern-day crimes: (1) information communication technologies (e.g., Desire to Learn platform, Zoom, mobile apps); (2) human-computer immersive environments (e.g., Artificial Intelligence, blockchain, machine learning, and metaverse); (3) forensic information management systems to store, retrieve, and update biometrics and criminal data (e.g., fingerprints, DNA profiles); and (4) forensic analytics— an emerging career combining forensics, computers, and data science, applying investigative techniques and analytical tools to identify patterns and criminal behavior (Koroniotis et al., 2019).

Under the 2018 NSF ITEST grant, UCO's research and development (R&D) effort aimed to train 150 rising high school junior and senior girls through three rounds of CS4Girls Academy experiences, and support opportunities for 30 of them to participate in independent career explorations (e.g., internships and research-fellowship). UCO staff, contractors, and partners developed the resources, methods, and technologies to deliver the model. The project leveraged partnerships with a variety of university, industry (e.g., Apple), and government/law-enforcement agencies at the city (Edmond Police), state (Oklahoma State Bureau of Investigation), and federal levels (e.g., the FBI), in a coordinated effort to inform design of the program, provide experts to contribute to CF4Girls Academy activities, and facilitate connections through which participants might secure independent learning opportunities. The consultant research team studied the model and its development (Knestis et al., 2022).

Rationale & Focus of this Paper

Gender Gap

Women in the United States are underrepresented in technology-focused professions, with barriers to equity including gender-related social influences (e.g., stereotypes, values, or role beliefs), and a lack of opportunities and support for girls navigating education pathways to such careers (Glass et al., 2013; Keune, Peppler, & Wohlwend, 2019). The project team designed the CF4Girls Academy to align with emerging careers as diverse as AI Engineer, Cybersecurity Specialist, Data Scientist, Forensic Examiner, and Information Analyst (Billionniere & Rahman, 2020; Fitzgerald et al., 2014; Mew, 2020).

Skill Gap for the Emerging Fields

Computer Forensics (CF) is an interdisciplinary subfield of forensics that applies technologies and analytic methods to gather and preserve evidence from compromised networks or computers, and UCO's approach responds to a growing need for CF professionals resulting from increased reliance on technology, costs of cybercrimes, and skill gaps (e.g., Choo, 2008; Morgan, 2019; U.S. United States Cyber Command, 2015). In addition to the CF lens, the CF4Girls Academy leverages data-centric theme through which girls examine STEM discipline content more broadly, and as thematic context for widely applicable learning

outcomes—generalizable STEM, information systems, and communication technology (ICT), workplace skills for emerging fields and understandings on the human-computer frontier. Inciter intended the research to expand collective understandings of how the theories of action informing features of the STEM CareerBuilder innovation (and driving NSF’s ITEST program) translate into a feasible OST program for girls and realization of desired workforce outcomes (McCreedy and Dierking, 2013; National Research Council, 2012; Reider, Knestis, and Malyn-Smith, 2016).

Convergent Framework

Computer Science (CS) an evolving discipline, lays the foundational knowledge and fosters computational thinking (CT) and analytical skills for solving modern-day problems (e.g., cyber security) innovatively.¹⁻¹⁰ UCO designed the CF4Girls with a data-centric lens to prepare girls with interdisciplinary knowledge and transferrable skills for emerging careers (e.g., Computer Forensics, Data Science).⁵⁰ While workforce with AI and Data Science expertise are in high demands, the pathway for education and careers are still being explored and defined.⁹⁴ Recent research in 2023 by the Gates Foundation shows that lack of career awareness especially impacted minoritized girls who are Black, Hispanic, and Indigenous (Bill and Melinda Gates Foundation, n.d.).⁹⁴ Thus, promoting career awareness and interest among the underserved with intersectionality is important to promote equity, diversity, and inclusion.⁹⁴

METHODOLOGY

Research Questions

As a holistic, mixed-method study, the research team elected to apply the DDR research design from options delineated by the NSF and U.S. Department of Education (Institute of Education Sciences, 2012) to address a broad set of questions to (1) inform ongoing development of the STEM CareerBuilder model, and (2) to test its promise of impact. This article presents results of one component of that research effort—the quantitative outcome analyses pursuing the second of those aims, framed around one key research question:

1: How does the CF program as a whole (the CareerBuilder model; annual CF4Girls Academy plus four interventions) further targeted outcomes for participants?

Importantly, the project team adapted the CF4Girls Academy model for content delivery under Covid-19 restrictions in the spring of 2020, including by the addition of questions addressing programmatic changes necessary in response to pandemic restrictions. The project team added the following questions—those examined through quantitative outcome data:

2. How are elements of the CF Program model being adapted for fully online delivery, post-Covid 19:

3. How does the CF Program in its fully online form compare to the previous year’s hybrid model in terms of furthering targeted outcomes for participants?

Activities for the four-year project began in March of 2018 with research over the first 18 months of the project contracted to the firm then managed by Kirk Knestis, Ph.D., DDR study designer for the proposal to NSF. The research contract was transferred to Inciter in October 2019, following Dr. Knestis to the new firm. NSF also granted the UCO project a 1-year, no-cost extension due to exigencies of the Covid-19 pandemic, extending the completion date of the project to February 2022. Dr. Knestis managed research activities through project closeout.

Study Design, Setting, and Participants

The research team designed outcome data collection and analyses to establish evidence of the potential of the STEM CareerBuilder model to increase girls’ STEM career awareness, interests, motivation,

technical and job skill competencies, as well as their inclinations to pursue and persist in STEM education-workforce pathways. The research team collected data over four implementations of the CF4Girls Academy—as a pilot in 2018, then through iterations as changes to the model were informed by R&D feedback and changing Covid-19 pandemic restrictions.

2018 Crime Scene Investigation Pilot

The one-week pilot (August 2018) examined what was then the Criminal Justice summer program, the prototype learning model based on UCO's previous work in Forensics and STEM educational programming. The program used a summer camp OST structure, testing initial design of activities to boost STEM workforce outcomes among underserved high school students. Twenty-four students, both male and female, participated that summer. Seventeen additional students applied but were not granted one of the limited slots in the pilot. They served as a comparison group for analysis examining differences in outcomes between participants and nonparticipants, and between students self-identifying as male and female. Results from the pilot informed development of materials and technologies for the CF4Girls Academy and for testing and improvement of research instrumentation including a pre-post assessment of student outcomes developed by the research team.

2019 Hybrid CF4Girls Academy

UCO hosted the initial, full version of the CF4Girls Academy as a 2-week summer camp in May and June of 2019. The expanded curriculum consisted of a “hybrid” of hands-on, in-person investigative activities and online learning, as envisioned in their NSF ITEST proposal (National Science Foundation, 2017). The new model included substantive changes over earlier efforts, the most fundamental being its re-conception as an all-girl experience, based on a finding from the CSI pilot that female students consistently outperformed males in targeted STEM workforce outcomes in the CF4Girls Academy model (Cheng & Feng, 2018). The project team decided to target girls for participation based on oversubscription of applicants relative to the project's limited funding (e.g., only 10% of female applicants could attend the state-funded summer program). The idea was to increase girls' opportunities in this NSF-funded program by directly addressing the problem of gender underrepresentation in the STEM education pathway, increasing equity to grow a diverse, skilled, and innovative workforce (National Research Council, 2002).

In-person activities included career presentations, hands-on crime scene preparation and evidence collection, visits to Oklahoma State Bureau of Investigation crime labs, explorations of forensic science technology (e.g., AI, blockchain, databases, and machine learning), and team-based efforts to solve a fictional murder case (e.g., through metaverse and virtual interviews of role-played suspects). Group meals and overnight stays in the UCO dormitories aimed to deepen the 2019 CF4Girls Academy experience for the 49 high school girls randomly selected from a pool of more than 200 interested applicants. Nonparticipants again served as a comparison group.

2020 Online CF4Girls Academy

With the 2020 CF4Girls Academy scheduled for mid-July, Covid-19 restrictions made it necessary to modify the course on very short notice, with new virtual learning resources and technologies developed between March and June for fully online delivery. As much of the CF4Girls Academy was virtual from the outset, built on a reliable online teaching platform, it was still possible for UCO to host the course. However, it was necessary to fundamentally modify a number of in-person CF4Girls Academy elements for remote execution (e.g., virtual crime scene investigation), and to remove some altogether (e.g., taking shoe imprint castings, collecting blood samples from a physical crime scene) as not translating effectively to virtual delivery.

Participants first completed a week-one online CSI course from the National Forensic Science Technology Center (NFSTC) at Florida International University (FIU). For week two, the project team designed a series of web-mediated, integrated learning activities to engage CF4Girls Academy students. These activities included presentations by experts in forensic sciences and related fields, team-based activities in which students role-played investigators working a murder case, explorations of digital

technologies related to forensics, and development of products reflective of their learning. The CF4Girls Academy culminated in online presentations of teams' cases against the suspect they identified as culpable for the fictional murder central to the curriculum's thematic approach.

Due to challenges in recruiting for an online OST learning program during the emergence of Covid-19, the 2020 CF4Girls Academy had only 16 participants (two investigative teams). This precluded inclusion of a nonparticipant comparison group in the research; a sampling strategy possible only when the CF4Girls Academy was oversubscribed. Perhaps more importantly, Covid-related constraints dramatically complicated engagement of participants in job shadowing, mentoring, internship, and research fellowship activities designed into the model, compromising opportunities built into the model for girls to benefit from female role models in industry and government (Fifolt & Searby, 2010; National Science Board, 2018). The project team placed a greater emphasis on these interventions in 2020, only four girls having secured placements following the 2019 summer session as internship sponsors withdrew their participation due to Covid-19. The shutdown restrictions made that impracticable, with only two girls securing internship placements in 2020 and five in 2021 (three internships, two fellowships).

2021 Online CF4GirlsAcademy

Delivery of the 2021 CF4Girls Academy was essentially identical to the model applied the previous year, with activities facilitated fully online in late July. The online CSI course again made up the first week, with virtual team forensics activities taking place the second week of the course. Eighteen girls participated in this final summer CF4Girls Academy, made possible by NSF's 1-year continuation of the ITEST project. No comparison group was available for 2021.

Instrumentation

In effect, because STEM CareerBuilder—with independent career investigations layered onto the CF4GirlsAcademy—was not implemented in its entirety in any of its three post-pilot years, the study-as-implemented is most accurately an investigation of the CF4Girls Academy essentially as a standalone learning program. Not enough girls completed internships or research fellowships during Covid-impacted years for Inciter's research to make any substantive inferences about the influence of those components on targeted outcomes.

Appropriate to a DDR study, the research team collected mixed (qualitative and quantitative) data across all four years of CF4Girls Academy evolution, with data-collection strategies modified to accommodate collection by fully remote means. However, all data-collection instrumentation remained the same in terms of substance and content assessed over the three years of post-pilot CF4Girls Academy research.

CF4Girls Summer Academy Pre-Post Questionnaire

The research team adapted a questionnaire piloted during the 2018 Criminal Justice summer program to assess self-reported outcomes; a pre-post design being employed to test for gains from engagement in the CF4Girls Academy. Constructs examined include (1) awareness of STEM and CF careers, (2) interests in STEM and CF careers, (3) motivation, (4) soft skills, and (5) technical competencies. Participants' education and career goals were also assessed, as were impressions of summer program quality and delivery. The research team constructed items using response sets that could serve as scales for analysis, with multiple items constituting the awareness, interest, motivation, and competency constructs of interest. This allowed calculation of both item-level and composite differences (e.g., means of item scale scores), pre-to-post CF4Girls Academy.

Online CSI Course Assessment

Girls participating in the 2019-2021 Academies also completed an assessment of Crime Scene Investigation (CSI) knowledge career competencies, embedded in the FIU NFTC online course provided for the full CF4Girls Academy model. This 16-hour, self-paced *Introduction to CSI* course is designed for new investigators and first responders, to teach guidelines for crime scene processing and evidence

collection. The online CSI course is aligned with professional standards of practice and delivered through FIU's online content management system (CMS). Students who scored a minimum 60% correct score on the post-CSI assessment received a certificate of completion. Forensic topics examined include (1) physical evidence, (2) crime scenes, and (3) evidence collection. The latter assesses understandings relating to six types of evidence: Biological, Trace, Latent Print, Footwear and Tire Track, Tool and Toolmark, and Firearms. The project PI downloaded scores from the FIU CMS for analysis. Data from this instrument was analyzed to assess technical competency outcomes defined for the STEM CareerBuilder model. No nonparticipant comparisons were available for this data and completion rates neared 100% each year.

Other Design and Development Research Data Sources

The research team incorporated additional data-collection strategies into the DDR study, primarily to inform year-to-year improvements to the STEM CareerBuilder program and delivery. The pre-post CF4Girls Academy questionnaire included a number of open-ended items that were analyzed through qualitative content analysis but limited in use to informing program-improvement decisions.

The research team also added a post-CF4Girls Academy, follow-up Longitudinal Questionnaire in 2020, to determine how desired outcomes persist over time for CF4Girls Academy alumnae. The research team hoped to track STEM- and CS-related outcomes through their late high school and early postsecondary years, but responses were too few for analysis and consideration here.

Researchers also observed in-person learning activities during the 2019 CF4Girls Academy, providing first-hand understanding of program processes, contexts, and student learning. Following the shift to fully remote delivery of the Covid-adapted CF4Girls Academy model for 2020 and 2021, researchers observed learning activities, including student teamwork and presentations, as participants in the Zoom-based work environment facilitating online sessions.

The research team also facilitated multiple rounds of virtual interviews (as individuals, pairs, and small groups), to collect narrative records of participants' post-CF4Girls Academy impressions (all years, 2019-2021) and to better understand influences on engagement in the job shadowing, mentoring, internship, and fellowship activities originally intended for the STEM CareerBuilder model. The research team reported analysis results from these additional methods annually to the PI for program-improvement purposes, and summarized in a comprehensive closeout report, but are also not examined here.

Data Collection

Protection of Human Subjects

UCO's Institutional Review Board (IRB) oversaw all data-collection activities, with initial approval secured prior to the award of NSF funding. The PI renewed the IRB coverage annually, with study design and instrumentation updates provided for review, and all study procedures adhered to federalwide standards for the protection of human subjects in research. The project team secured informed parental consent and participant assent for all data-collection strategies by collecting IRB-approved forms as part of the Academy registration process, allowing data collection from minor participants including in the comparison pool.

2018 Pilot Pre-Post Data Collection

Participants completed the web-based pre-survey at the beginning of the 2018 CSI Pilot and the post-survey at the end of the 5-day CF4Girls Academy—both through email invitations. Students who applied but were not selected to participate completed a questionnaire identical to the pre-survey completed by CF4Girls Academy attendees. All 24 participants completed the pre-survey and 21 completed the post-, while 17 nonparticipants voluntarily submitted data for comparison analysis.

The research team performed reliability analyses using data collected by these means, to ascertain the consistency of measures and validity of constructs of interest to improve instrumentation prior to use with the 2019 cohort. The research team also examined internal consistency using item deletion analysis, with between-item correlations and Cronbach's alpha values calculated for each scale. The research team combined participant pre responses with nonparticipant responses for these analyses, as no selection criteria

purposefully separated the two groups. The project team considered post responses separately. Cronbach's alpha values of 0.70 or higher were defined as "good."

The only substantive revision to the pre-post questionnaire following pilot analysis was to fully delineate between STEM and CF in outcome domains. The research team transposed items with both disciplines in a single measure into separate indicators. Ultimately, only very minor edits beyond these few post-pilot changes were made for 2019-2021, with no substantive modifications of the pre-post instruments.

2019 Pre-Post Data Collection

The research team administered the revised pre-post survey to participants around the 2019 CF4Girls Academy. The number of participant slots was doubled to 50 but drawing them still left a large group of nonparticipants as a comparison group. The 90% pre-survey completion rate was observed among the 50 participants; 68% completed the post-survey. Twenty-two of the 160 comparison students completed their questionnaire, again the same as submitted by participants. All applicants for the 2019 CF4Girls Academy self-identified in registration forms as female.

2020 Pre-Post Data Collection

The research team administered the outcome questionnaire, essentially unchanged from the previous year, online to participants at the beginning and end of the now-virtual CF4Girls Academy. The research team allocated time during the course lectures for students to complete this year's questionnaires, to help improve response rates and allow students to ask questions if necessary. This strategy, as opposed to instructing participants to complete the questionnaire outside of CF4Girls Academy time, resulted in improved response rates. It may also have improved response quality, as several participants did ask clarifying questions about items and a few technical difficulties were resolved in real time. The pre-survey produced 13 responses (93% of registrants); the post- getting 14 (100%). One record was incomplete so had to be excluded from pre-post change analysis, as was the record missing pre- data, the result being 12 records for pre-post inferential testing. Decreased registration numbers meant that participants were not drawn from a pool of applicants, so no comparison group was available for 2020. All research participants identified as female.

2021 Pre-Post Data Collection

Instrumentation and data-collection processes for the 2021 pre-post survey were essentially identical to those employed the previous year. Of the 19 girls enrolled in the course, one opted to not take part in the study. Seventeen pre-surveys and 16 post-surveys were submitted. However, one participant completed the pre twice, while another completed the post twice. Responses were not the same for the duplicate submissions, the research team excluded the data from analysis, leaving 15 valid pre- and 14 valid post-surveys, of which only 12 were matched pre-to-post. As the previous year, the program was undersubscribed so there was no comparison group for 2021 and again, all participants were female.

Data Analysis

Analysis plans required matching participants' pre- and post-program responses using a unique identifier developed for each student to use when completing questionnaires. The research team performed paired-sample *t*-tests to compare pre- and post-CF4Girls Academy scores, to assess group gains for both item and composite scores. Analysts also performed independent-sample *t*-tests on the same questions between participant posttest responses and nonparticipant responses for the years for which comparison groups were available.

It must be noted that most assumptions typically expected for *t*-tests were not met for these analyses (e.g., random sampling and sample size in 2020-2021; normality for all years). This is, however, an arguably tolerable shortcoming given the modest intentions for DDR studies regarding causality; that they "draw on existing theory and evidence to design and iteratively develop interventions," and generate results that "could lead to additional work to better understand the foundational theory behind the results or could

indicate that the intervention or strategy is sufficiently promising to warrant more advanced testing” (Institute of Education Sciences 2012, p. 9).

RESULTS

Sections below present discussion of what the project team learned about STEM workforce teaching and learning from the patterns of significant outcome gains over the four-year period.

Interpretation of results that follow should consider that the CF4Girls Academy evolved substantively over the life of the project, so a truly longitudinal or repeated-measures view of findings is not appropriate. Thus, the quantitative analyses of pre-to-post and group differences are applicable as it is acceptable given the intended aims of the study and methodological limitations of the Design and Development Research (DDR) model applied to the team’s research (IES USED & NSF, 2012).

Career Awareness

Outcomes relating to participants’ awareness of STEM and CF workforce opportunities showed near-universal statistically significant pre-to-post gains over all four years of the project (Table 1). Significance was not evident for only one item (re: career opportunities in STEM) for one year of implementation (2020). Note that “NA” indicates where an item was not included in the questionnaire as a result of revisions of the instrument following pilot analysis. Summer program participants clearly learned about what STEM and CF professionals do and about opportunities that they might pursue. This finding was consistent irrespective of the evolutionary changes to programming over the life of the study.

TABLE 1
PRE-POST CAREER AWARENESS

Career Awareness	Checked When Significant ($p < 0.00$)			
	2018	2019	2020	2021
	Ground	Hybrid	Virtual	Virtual
	CF4Girl Academy			
I am aware of career opportunities in [STEM].	✓	✓	-	✓
I understand what STEM professionals do.	✓	✓	✓	✓
I am aware of career opportunities specific to CF.	✓	✓	✓	✓
I understand what CF professionals do.	✓	✓	✓	✓
I am aware of CF internships.	NA	✓	✓	✓
I am aware of STEM research opportunities.	NA	✓	✓	✓
I am aware of CF research opportunities.	NA	✓	✓	✓
Career Awareness Composite	✓	✓	✓	✓
STEM Career Awareness Composite	NA	✓	✓	✓
CF Career Awareness Composite	NA	✓	✓	✓

Career Interests

In stark contrast to awareness outcomes, findings revealed that the pre-to-post gains for program participants’ STEM- and CF-related career interests were only significant for a very few outcomes, and

then only intermittently over the duration of the research grant, as illustrated in Table 2. Additional insights on factors (e.g., self-select with already high career interest) contributing to the findings will be presented in Section #4 Discussion.

TABLE 2
PRE-POST CAREER INTERESTS BY YEAR

Career Interests in STEM	Checked When Outcome Differences Found to be Significant ($p < 0.00$)			
	2018	2019	2020	2021
I am interested in pursuing a higher education degree in STEM.	-	✓	-	✓
I am interested in pursuing a STEM career.	-	✓	✓	✓
Career Interests Composite	-	-	-	✓
CF Career Interests Composite	NA	-	-	✓

Only the much broader “interest in pursuing a STEM career” consistently showed evident gains—and then, only after the transition post-CSI pilot implementation to the CF4Girls Academy model. While difficult to measure narrowly defined items and show significant growth, the research team noted that participant’s pre-CF4Girls Academy interests were already high due to the self-selected bias. The gains derived from the pre/post-CF4Girls Academy were too small to result in statistical significance.

Motivation

Similar to career interest, findings revealed that the pre-to-post gains for program participants’ motivation were not significant since students self-selected themselves to apply and attend the CS4Girls Academy, as illustrated in Table 3.

TABLE 3
PRE-POST MOTIVATION BY YEAR

MOTIVATION	Outcome Differences Found to be not Significant, as denoted with a dash			
	2018	2019	2020	2021
Motivation Composite	-	-	-	-

Career Competencies (Knowledge, Soft Skills, and Technical Abilities)

Forensic Knowledge

The assessment built into the online CSI course completed by girls in the 2019, 2020, and 2021 **CF4Girls Academy** cohorts serves as an additional measure of participants’ gains in technical career competencies, specifically regarding understandings of the processing of crime scenes and collection of evidence (Table 4). Results from analyses of this course-embedded, online test—large and significant changes, pre-to-post ($p < 0.00$)—reinforce that female high school students can effectively gain specialized forensic science understandings from the independently completed, postsecondary-level online course included in the CF4GirlsAcademy model, per Table 4 (2019, 2020, and 2021 respectively).

TABLE 4
PRE-TO-POST KNOWLEDGE DERIVED FROM THE ONLINE CSI COURSE ASSESSMENT

CSI Career Competencies			
	<i>t</i>	Df	<i>p</i>
2019 CSI Online Course Outcomes Percent Correct	8.9	48	0.00
2020 CSI Online Course Outcomes Percent Correct	8.59	13	0.00
2021 CSI Online Course Outcomes Percent Correct	-8.8	10	0.00

Soft Skills

Similar to career interests and motivation, increases in soft skills were small without statistical significance (Table 5).

TABLE 5
PRE-TO-POST SOFT SKILLS

Professional Career Competencies	2018	2019	2020	2021
Entrepreneurship	-	✓	✓	-
Critical thinking	-	✓	-	-
Problem solving	-	✓	-	-
Teamwork	✓	-	-	-

Technical Abilities Career Competencies

Examination of year-by-year analyses of career competency outcome gains is presented in Table 6, by outcome domain defined for the model. A check mark signifies where **CF4GirlsAcademy** participant pre-to-post gains (by outcome) were determined to be significant. Outcome differences by year denoted by a dash were not found to be significant.

TABLE 6
PRE-POST COMPETENCIES BY YEAR

Technical Competencies	Checked when Significant			
	2018	2019	2020	2021
Cybersecurity	✓	✓	-	✓
Forensic biometrics	✓	✓	✓	✓
Computer databases	✓	✓	✓	✓
Computer programming	✓	✓	✓	✓
DNA	✓	✓	-	✓
Blood testing	✓	✓	✓	✓
ICT technology	✓	✓	✓	✓

Media technology	✓	✓	-	✓
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Self-Efficacy and STEM Education Goals

Significant pre-post differences were observed for a number of targeted STEM-related self-efficacy variables, for all three years of the CF Academy. However, beyond consistent gains in participants feeling that they are “good at computer forensics,” patterns do not illuminate any clear insights (Table 7).

TABLE 7
PRE-POST SELF-EFFICACY BY YEAR

Self-Efficacy and Career Goals	Outcome Differences Found to be Significant			
	2018 CSI	2019 CS	2020 CS	2021 CS
I am good at computer forensics.	-	✓	✓	✓
Even if the computer forensics work is hard, I can learn it.	-	-	-	✓
I can master the computer forensic skills that are taught.	-	-	✓	-
I am willing to learn challenging topics in STEM at my school.	-	-	-	✓
My career will involve STEM.	-	✓	-	✓
I will use STEM problem-solving skills in my career.	-	✓	-	-
Composite, overall	-	✓	NA	NA
Composite, self-efficacy only	-	✓	NA	NA

Broadly speaking, participants made either substantial gains (technical competencies, career awareness) from Academy activities, or gained little (all other domains). It is further informative to understanding gains for girls on the STEM CareerBuilder pathway to consider the *lack of differences* in self-reported outcomes between participants and individuals who applied for the program but were not selected to participate. Oversubscription made such comparisons possible in the 2018 CSI pilot and in 2019, the first CF Academy and only one not impacted by Covid-19.

Independent *t*-tests comparing participant *post survey* results with nonparticipants’ scores on the same instrument illuminate which gains from among those above might reasonably be attributed to UCO’s intervention. It is notable that significant item-level differences between participants and nonparticipants were either *very rare* or *nearly universal* depending on the outcome domain. Table 8 lists the specific outcomes for which significant differences were identified, by domain.

Considering differences between participant and comparison girls shows that the two groups were largely equivalent *after the program* for the outcomes that the CF4Girls Academy did not change. These outcome variables, at whatever level they were measured pre-program, can be thought of as factors that applicants for the STEM CareerBuilder program brought with them to an application process that was arguably biased through recruiting outreach strategies toward selecting participants with those qualities. For girls randomly selected to participate, the intervention did not grow those competencies. The STEM CareerBuilding pathway sorts girls into the program who are predisposed toward general career competencies, and interests and motivations toward STEM careers into the program; then effectively grows their technical competencies and awareness of specific career opportunities.

TABLE 8
SIGNIFICANT DIFFERENCES BETWEEN PARTICIPANT AND
NON-PARTICIPANT GROUPS

Post-CF4Girls Academy Outcome Domain (Self-reported)	Outcome Domains with Significant Differences, Participants vs. nonparticipants	
	2018 Criminal Justice Pilot	2019 CF4Girls Academy
Career Awareness (Table 1)	All outcomes except Awareness of STEM and CF research opportunities, including the composite	All outcomes except Awareness of STEM internships and awareness of STEM research opportunities, including the composite
Career Interests (Table 2)	None	None
Motivation (Table 3)	None	None
Knowledge from the CSI Online Course (Table 4)	N/A	All outcomes
Soft Skills (Table 5)	None	None
Technical Abilities (Table 6)	Forensic biometrics, DNA, and blood testing	All outcomes
Self-efficacy and Career Goals (Table 7)	None	“I am good at computer forensics,” “I like computer forensics,” and the composite outcome that includes those two outcomes

DISCUSSION

These findings should also be considered in the context of adaptation for safe delivery under Covid-19 pandemic restrictions. This is possible given the two additional questions framed mid-project when it became apparent that the STEM CareerBuilder would have to be adapted to restrictions imposed as a result of pandemic conditions.

Adaptation for Online Delivery

RQ #2. *How are elements of the CF Program model being adapted for fully online delivery, post-Covid19?*

That implementation of the 2020 Covid-safe, fully remote CF4Girls Academy model was even possible is testament to qualities inherent to the technology-enabled tools that were already part of the STEM CareerBuilder curriculum. The fact that outcome domain gains were not lower after the transition to the fully remote delivery model—and were in some instances higher—argues that the fully remote adaptation of the CF4Girls Academy shows potential for efficacy similar to that of the original blended CF4Girls Academy model.

AI-powered Simulations Developed with Metaverse

Specific online program components to immerse girls with web-based murder investigation activities using metaverse and virtual reality (VR) in simulated (SIM) learning environments included (1) the *Triage 911 Center* (allowing participant team members to simulate responding to an incoming call for public safety services); (2) a virtual reality to role play as an investigator; (3) a *Crime Scene with victims*; and (4) a simulated *Detective Office*, including tools for communication and collaboration during team investigations (Figures 2, 3, 4, and 5). Research shows that role playing can foster career identity (Yao, 2023).

FIGURE 1
E-TRIAGE 911



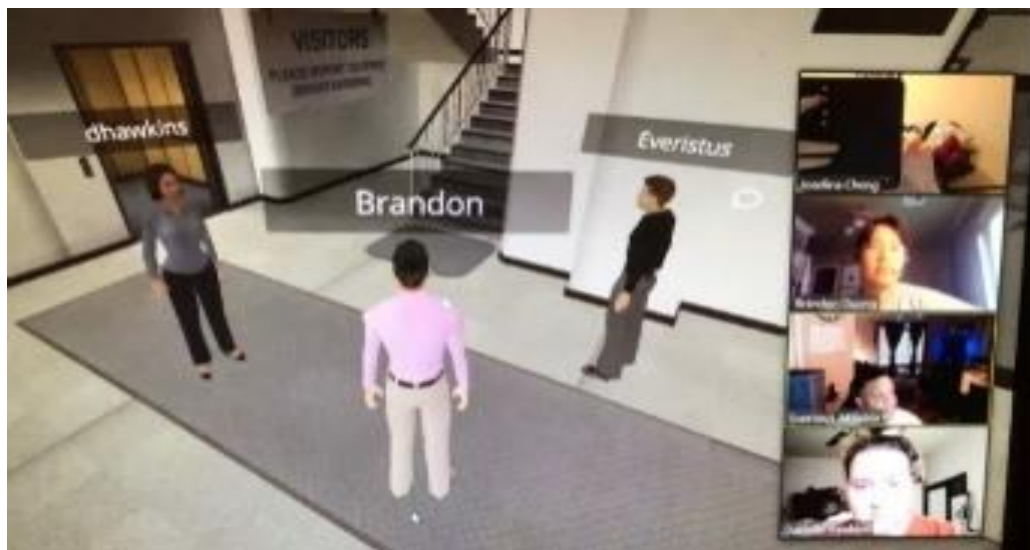
FIGURE 2
VR



FIGURE 3
E-CRIME SCENE



FIGURE 4
E-DETECTIVE



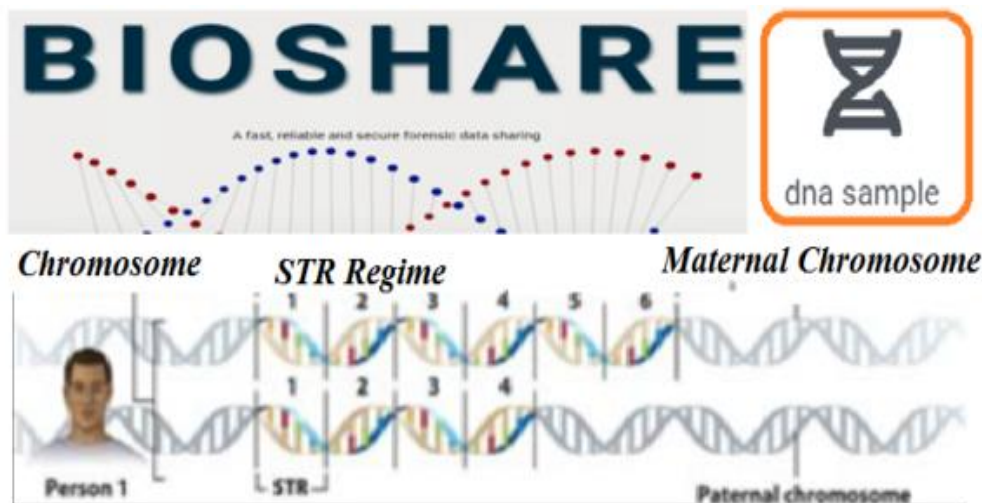
AI-powered Analytic Tools for Solving Modern-day Crimes

Girls also used two innovative tools to solve crimes. First is the simulated Forensic Biometrics Engines (**Figure 5**), which was built with AI and trained with criminal data. Girls used this automated engine to search a simulated information system which is similar to the Automated Fingerprint Identification System (AFIS). Second is the Bioshare system (**Figure 6**), which was built with blockchain to securely transfer DNA data. Girls learned how blockchain technology, which is often associated with crypto currency, can also be implemented to manage chain-of-custody assurances for evidence to retrieve forensic evidence from the Combined DNA Index System (CODIS).

FIGURE 5
UCO'S BIOMETRIC SEARCH ENGINE (DEVELOPED WITH AI & MACHINE LEARNING)



FIGURE 6
UCO'S BIOSHARE OF DNA (DEVELOPED WITH BLOCKCHAIN)



AFIS and CODIS are the generic terms used to describe the FBI's program of support for criminal justice databases as well as the software used to run these databases. These components translated seamlessly to the 2020 Covid-safe virtual CF4Girls Academy model. The online CSI course translated directly from the hybrid to fully online models as well, with participants given access codes to attend classes virtually and take an online exam.

Online Modality

Components that were implemented in 2019 as part of the resident camp portion of the CF4Girls Academy included introductions to job shadowing and mentoring; CSI strategies, physical sample collection, biometrics of footprints and fingerprints, and artifacts and patterns of solving crimes. These, plus presentations and coaching from STEM and computer forensics professionals were translated into web-based equivalents in the weeks between the outbreak of Covid-19 and the first fully virtual CF4Girls Academy.

The 2020 CF4Girls Academy was delivered using Zoom, with participants provided with other tools for web- and wireless-device communications (e.g., GroupMe). Mornings of the first four days of “virtual camp” included live and pre-recorded presentations from STEM and CF professionals; while afternoons were divided between (1) mock investigation activities (from responding to the initial call reporting a murder to 911, through virtual evidence collection and interviewing of witnesses (roleplayed by facilitators); and (2) team investigation time facilitated by a teacher leader. The final half day was reserved for presentation of the case prepared by each team, laying out their resolution of the crime under investigation.

Comparing Online to Hybrid Delivery Models

RQ #3. *How does the CF Program in its fully online form compare to the previous year’s hybrid model in terms of furthering targeted outcomes for participants?*

Review of year-to-year analyses of outcome data (see the tables above) shows little difference between results for the pre-pandemic version of the CF4Girls Academy (summer of 2019) and its post-outbreak, fully online evolution (2020 and 2021). The number of significant gains in technical career competency dip very slightly in 2020 but rebound completely for 2021. As might be reasonably expected, outcomes specific to the online CSI course component of the model were not impacted by transitions of other content delivery to virtual environments. However, the limited gains in professional career competencies/soft skills (e.g., team collaboration) evident in 2019 (in-person CF4Girls Academy attendance) were not present in the last two years of the program (virtual attendance), suggesting challenges growing interpersonal workplace skills when interacting only through web-based communication tools.

Also interesting was the finding that more targeted outcomes in the domain of motivation were found to be significantly better for participants in the 2020 fully online CF4Girls Academy, than for the 2019 hybrid model that included in-person STEM learning activities. It is worth repeating here that recruiting processes (and success) changed substantially under Covid-19 restrictions, and the number of applicants for summer programming dropped dramatically. This may have fundamentally changed year-to-year the profile of the students who ultimately participated in the CF4Girls Academy—if not in terms of their interest *coming into the program*, then perhaps in their capacity to become more motivated *by the program*. This dynamic might also help explain how the pattern of gains across self-efficacy outcomes changed, even if the number of outcomes found to be significant ultimately did not increase much over the multi-year CF4Girls Academy implementation.

Perhaps the most notable finding—or at least most consistent—is that, while UCO’s forensic science workforce teaching-and-learning innovation almost universally increased participants’ awareness of STEM career options, findings revealed that participant career interests did not increase significantly. The programming exposed girls to emerging career opportunities (e.g., forensics analytics), but it did not make the majority of the participants care more about forensics over the two-week CF4Girls Academy period. Findings, likely contributed by the self-selected bias, suggested the lack of (1) interest item gains pre-to-post, and (2) measures of no differences between participants and comparison applicants in 2018 and 2019. While the lack of significant increases in career interests was consistently the case even across the transition from the hybrid in-person/online model to the fully virtual, Covid-safe, Zoom-and-web-tools version of the CF4Girls Academy (2020 and 2021) with disruptive innovations. Female participants, who are generation Z, demonstrated their abilities to overcome technological challenges and performed well with significant increases in the: (1) content knowledge as derived from the online CSI courses and (2) technical competencies as derived from the pre/post-CF4Girls Academy surveys. This finding aligns with literature that generation Z are technologically savvy to excel in the virtual learning environments (Chicca & Shellenbarger, 2018).

CONCLUSIONS

This project has several positive implications in terms of replicating the model for a scale-up grant. First, online delivery is dramatically less expensive and easier to deploy than hosting multiple on-site, blended learning camp experiences for high school students. Virtual delivery eliminates constraints on participation due to geography (e.g., making engagement of students in rural areas much more practical). Second, while there were relatively minor differences in outcomes between the hybrid and fully virtual delivery modalities tested over the life of UCO's NSF ITEST project, the CF4Girls Academy seemed generally to be similarly efficacious when delivered fully online as it was in its resident camp mode. Since it was more accessible to participants (e.g., less expensive, reduced logistics of travel), this has implications for scaling up the STEM CareerBuilder approach. COVID-19 sped up digital transformation as e-teaching, e-learning, and e-working became the norms during the lockdown period. Underserved students, who are differently abled and neurodivergent, prefer access to recorded lectures (Horlin et al, 2023; Jarvis & Nordmann, 2020). Generation-Z also prefer online courses from their homes instead of incurring hefty expenses to live on campus (Mellman, 2020; Nauman, 2021). Likewise, corporations are now facing difficulties mandating employees to work in the office buildings, whereas working from home is a preferred choice (Liu et al, 2020). Thus, further developmental research along these lines with remote learning and working would frame a logical follow-on study of the model and its potential to reach more—and potentially the diverse and underserved—workforce development learner audiences.

This project also has limitations. First, the sample size is too small to generalize to the large population as this project assumed that students could be recruited to participate in such a program without any foresight of Covid-19. Low application numbers in 2020 and 2021 suggest that strategies to engage girls, as designed into the original STEM CareerBuilder, did not all translate well to purely remote application due to the pandemic. Next, many engaging activities, which were originally designed to enrich participants' learning experience with innovative technologies required in-person attendance to perform hands-on experiment (e.g., testing blood) in a physical forensic lab or solving crimes collaboratively in the evenings while living on campus to enrich college-like experiences. Low participation also highlights the issue of self-selection bias, sorting only students predisposed to pursue career-development opportunities in CF-related disciplines into the program. Since the aim is to get students who would not otherwise be so inclined onto a STEM workforce career pathway, exploring different recruiting strategies in the post-pandemic is also called for to further the project goal with larger population and a longitudinal study with higher post-program participation by focus groups. Explorations of factors that support or hinder teaching and learning in multi-modality environments can provide alternatives against further global disruptions (e.g., COVID-19) to better support our education systems and workforce preparation on the human-computer frontier.

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