The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #44023

Board 245: Does Integrating Innovative Technologies into STEM Education Help Advance K-12 Students' STEM Career Outcomes? A Synthesis Study

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Dr. Yue Li, Associate Director of the Discovery Center for Evaluation, Research, and Professional Learning at Miami University (Oxford, OH), has extensive quantitative research skills and experiences of leading research and evaluation projects related to systemic reform efforts, with specific proficiency in equitable and inclusive STEM environments. Over the last 17 years at the Discovery Center, Dr. Li has conducted research or evaluation for more than 60 STEM education related projects funded by NSF (e.g., projects funded through the ADVANCE, AISL, DRK-12, ITEST, IUSE, Noyce, STC, and STEM+C programs), state, and local agencies. She has experiences working as a member of the evaluation team on several projects focusing on engineering education at K-12 or post-secondary levels. She is currently serving as the PI of an NSF funded ITEST Synthesis project (Award #1949437), co-PI of an NSF-funded DRK-12 project (Award #2010351), Senior Personnel (mentor) of an NSF-funded RIEF project (Award #2306176), and the lead evaluator for numerous evaluation projects.

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Introduction

Funded through NSF ITEST program, the primary objective of this mixed-methods meta-analysis and qualitative synthesis study was to review and synthesize research and evaluation findings demonstrating the effects of integrating innovative technologies and technology-based learning experiences in STEM education on K-12 students' STEM career-related outcomes.

Objectives

This study synthesized the rigorous intervention research on Grades K-12 students' STEM career-related outcomes from 2000 to the present and across characteristics of innovative technology-based STEM education interventions, learning contexts, student demographics, and study designs. The purposes of this study were fourfold, to: 1) advance understanding of the effects of integrating innovative educational technologies and technology-based learning experiences into K-12 classrooms on students' STEM career outcomes; 2) enable generalization of the magnitudes and variations of effects on students; 3) specify what settings, technologies, and interventions have been effective for which groups of students; and 4) provide insights about how and why such interventions produced positive outcomes. Specifically, this study posed three research questions:

1. What are the magnitudes and variations of effects of integrating innovative technologies into K-12 STEM education on students' career-related outcomes?
2. What connections do participants make between students' STEM career outcomes and structural intervention characteristics of interventions involving innovative technologies, such as intervention duration, content areas, and targeted student grade levels?
3. What connections do participants make between students' STEM career outcomes and experiential features of interventions involving innovative technologies, such as lab-based research, mentorship, and career exploration?

Methodology

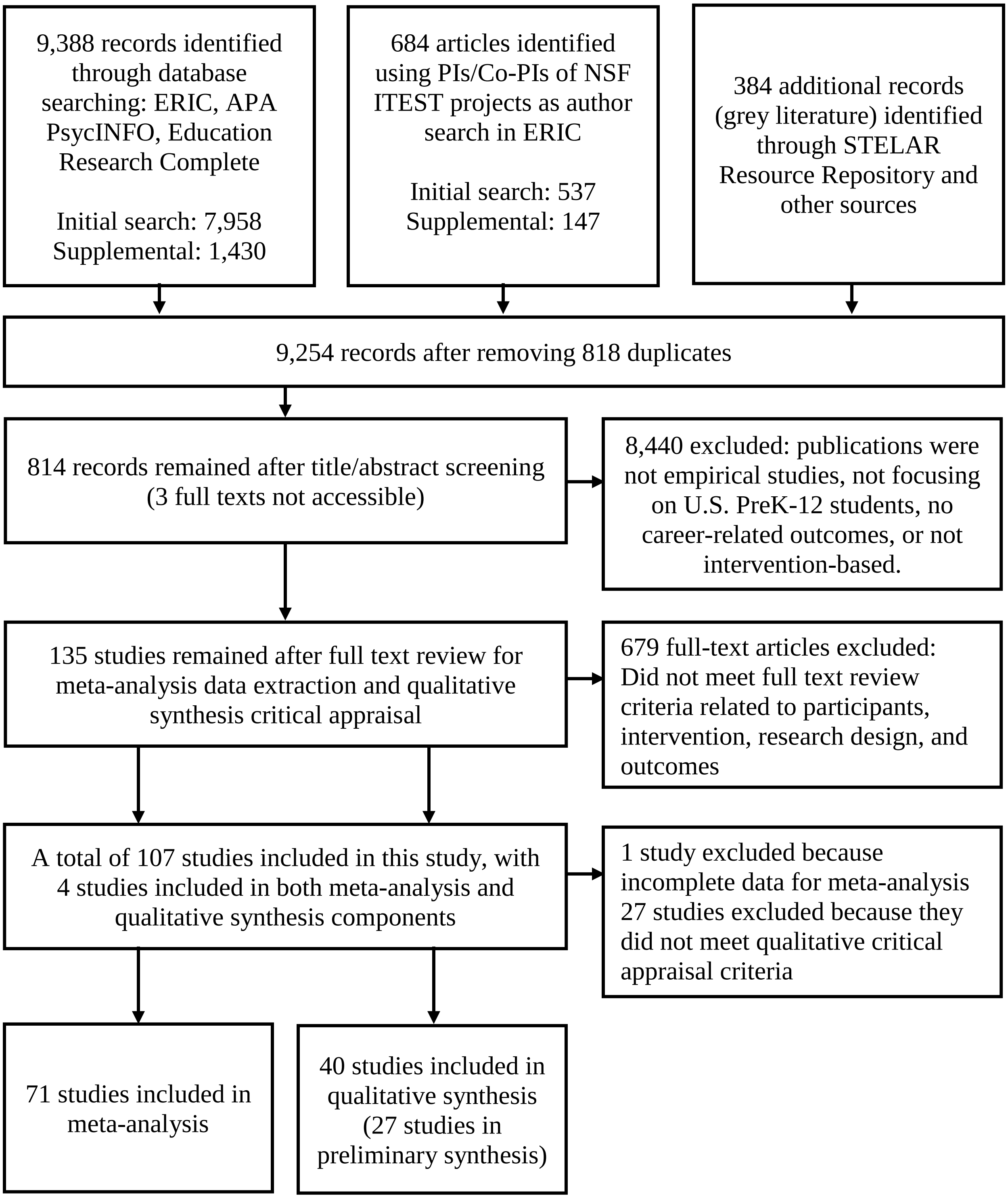
The method for conducting this study followed steps common to meta-analysis and qualitative synthesis studies. Initial research methods included establishing inclusion / exclusion criteria and search terms following the PICOS framework (i.e., participant, intervention, comparison condition/study design, outcome, and setting), conducting database searches, screening for study inclusion, coding, and conducting analyses. Databases searched included ERIC, Education Research Complete, and APA PsycINFO, all via EBSCOHost. In addition, STELAR Resources and ProQuest Dissertations and Theses were used to search grey literature.

Study participants were K-12 students or school-aged children who received direct or indirect STEM-related education interventions in the United States. Interventions included in the review focused on a broad-range of activities designed to improve STEM teaching or learning with innovative technologies. The researchers retrieved intervention content areas, intervention pedagogical practices, intervention durations (e.g., implemented for a unit, a semester, a year, or multiple years), and whether the intervention consisted of an explicit career development component (e.g., career counseling), from the primary studies. Intervention characteristics were coded as moderators for this analysis. This review utilized a broad definition of "career outcomes" in order to capture any study that should be included for meta-analysis. Following the work of STELAR scholars, STEM career-related outcomes were coded into four categories (a) dispositions, (b) knowledge, (c) skills, and (d) actions [1]. For example, attitude toward STEM careers was categorized as a disposition outcome, whereas career exploration was an action outcome. Study settings included primary studies conducted in formal settings or informal, out-of-school settings. Community contexts in which interventions were conducted included traditionally underserved communities. Intervention settings and community contexts were coded as moderators to understand how educational settings moderated the magnitude of intervention effects.

Screening steps included title and abstract screening, deduplication, full text retrieval, and full text reviews, all based on the PICOS eligibility criteria. Coding was based on a living codebook developed following "Cochrane Handbook for Systematic Reviews of Interventions" [2] and "Campbell Systematic Reviews: Policies and Guidelines" [3]. A PRISMA flow chart was created to illustrate the number of publications identified, included and excluded, and the reasons for exclusions (Figure 1). For the meta-analysis, design equivalent effect sizes were calculated for effects from single-group pre-post designs, two-group pre-post designs, and clustered RCT designs. R package metafor was used to conduct the meta-analysis to pool the estimated effect sizes across studies. Multivariate random-effect model using restricted Maximum Likelihood (REML) estimation and inverse variance weighting provided estimates of average effect size of the eligible studies, its variation, 95% prediction interval [4], and other heterogeneity statistics while taking dependency of multiple effect sizes into account.

For the preliminary qualitative synthesis, 27 articles and dissertations met all inclusion criteria. Quality review was based on a review checklist developed derived from the Critical Appraisal Skills Programme's checklist for appraising qualitative research [5]. Data were analyzed using thematic analysis to develop descriptive themes.

Figure 1: Prisma Flow Chart for Meta-Analysis and Qualitative Synthesis of Impact of Integrating Innovative Technologies in STEM Classrooms on K-12 Students' STEM Career Outcomes



Results

The preliminary meta-analysis involved 168 effect sizes from 71 primary studies, most published within the past decade. These studies encompassed an estimate of 14,911 student participants, primarily in upper elementary school to high school grade levels. STEM career-related outcomes were measured as dispositions, including interest, aspiration, motivation, confidence, and self-efficacy. A smaller number of studies also assessed knowledge in specific STEM careers. Overall, a small to moderate level of positive effect was observed (effect size mean = 0.379, SE = 0.064, 95%CI = 0.252 – 0.505, $p < .001$), with significant heterogeneity (Q (167) = 2418.355, $p < .001$), suggesting the need to explore potential moderator variables.

Intervention characteristics revealed that 58% targeted underrepresented and/or underserved populations, 41% included explicit career development, and interdisciplinary content was common. Additionally, 56% of studies took place in informal settings. The study also considered intervention format, duration, pedagogical practices, study design, and publication type as potential moderators in the final analysis.

The preliminary qualitative synthesis revealed that 21 of 27 studies reported student outcomes along at least one of two trajectories: students' prior STEM career interest was sustained or strengthened after participation in the intervention ("pre-existing STEM career interest") and students' STEM career interest was piqued by participation in the intervention ("direct impact on STEM career decision-making"). These STEM career outcomes were not clearly associated with any moderators related to intervention format, duration, pedagogical practices, or participants.

The finding of no clear patterns or relationships between the two STEM career outcomes examined and features of the intervention led to further exploratory analysis. Additional qualitative analysis suggested a subtle difference in STEM career outcomes in terms of the nature impact of the intervention. References collected under the "direct impact" code described students' reactions to their learning experiences as opening their eyes to possibilities for STEM careers, showing them a STEM career can be exciting and interesting, and revealing their true interests in highly impactful ways.

The references collected under the "pre-existing interest" described students' STEM career interests as strengthened or solidified after participation in the intervention, or, at the very least, unchanged. In comparison, references collected under a third code – "ability or enjoyment do not equal career interest" ($n = 6$) – described students as having fun, enjoying themselves but doubting their STEM aptitude, and even knowing they could potentially be successful in a STEM career after participating in the intervention. However, these references did not describe students' passions or interests being sparked at levels that influenced them to change their prior non-STEM career interests.

Conclusions

A small positive effect in the meta-analysis, combined with no discernible patterns that linked specific STEM career outcomes to specific combinations of moderators in the qualitative synthesis, suggests that increased interest in STEM careers can result from a variety of approaches to integrating innovative technologies into STEM interventions in formal and informal educational settings for pre-K-12 students. Differences in students' STEM career outcomes appear to relate to the extent to which students came to the experience with a STEM career interest and, regardless of their prior career interests, the extent to which enjoyment of the experience led to excitement about STEM careers that overshadowed prior career interests.

The idea that students' career interests can change over time when they are presented with novel experiences is not new [6], [7]. This study suggests that an intervention's ability to excite a student's passions in the context of an actual STEM career may be more important to influencing and supporting persistence in STEM career interests than any specific combination of programmatic features. Consequently, understanding students' perspectives about what excites them about STEM is crucial to program development, program evaluation, and supporting persistence through STEM career entry.

Future Work

Future plans for the qualitative synthesis are to analyze an updated sample of primary sources to examine the extent to which the themes identified in the first sample are upheld. Furthermore, the qualitative synthesis will result in analytic themes, which will enable interpretation of the nature of the relationship between STEM interventions and STEM career outcomes beyond a descriptive summary [8].

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