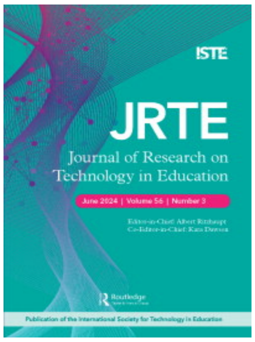

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Examining the impact on TPACK and knowledge subcomponents in dually certifying secondary mathematics teacher candidates with a Computer Science add-on endorsement

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ABSTRACT

This study examined the impact on secondary mathematics teacher candidates (TCs) TPACK knowledge and knowledge subcomponents of a two-course sequence based on the high school Advanced Placement (AP) Computer Science Principles (CSP) course leading to add-on teaching credentials for Computer Science (CS). We further examined the outcomes of Praxis II preparation modules on CS content knowledge of the preservice TCs compared to inservice teachers seeking an additional teaching field of CS. Our results indicate strong findings on the Technology Knowledge (TK) and TPACK factors for TC participants compared to their peers, as well as higher Praxis II scores than inservice teachers. We discuss the findings and implications for CS teacher certification embedded within other secondary teaching disciplines.

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TPACK; secondary mathematics teacher education; computer science teacher education; initial certification; Praxis exams

Introduction

Computer Science (CS) is expected to grow rapidly in the coming years (Google Inc. & Gallup Inc, 2016; Roberts et al., 2022). As CS education expands, especially in training math teachers, there will be a greater need for CS classes in K-12 schools. This means more qualified CS teachers are needed. Over the past two decades, the demand for CS teachers has grown (Computer Science Teachers Association, 2005, 2013; Zhu & Wang, 2023). However, fewer people are enrolling in preservice teacher programs, particularly in STEM fields (Belanger, 2017; Camera, 2019; Learning Policy Institute, 2018; Ofem et al., 2021; Partelow, 2019).

Many K-12 schools are addressing the immediate demand for more CS classes by relying heavily on professional development to train current teachers, mostly STEM teachers, in CS knowledge and skills, supplementing their primary teaching subjects. While this strategy mitigates the current supply-demand imbalance, it does not solve the long-term need for new mathematics teachers to be equipped with CS expertise from the outset, ready to teach both mathematics and CS from their first year.

Many studies and initiatives have called for CS preservice teacher certification programs (Gal-Ezer, 1995; Gal-Ezer & Stephenson, 2009; Khoury, 2007; The White House, 2016; Turner, 1985; Yadav & Korb, 2012). But there is little evidence of growth in the CS teacher pipeline or

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strong preparation programs. It is important to develop solid training paths and specialized teaching skills. There is also a push for preservice teachers (teacher candidates, or TCs) to be effective with technology after their training programs (Agyei & Voogt, 2011; Mouza et al., 2014). However, simply adding technology to these programs is not enough (Margaryan et al., 2011; Zelkowski, 2011a, 2013). Building specialized knowledge and skills, especially in technological pedagogical content knowledge (TPACK), is a challenge (Mishra & Koehler, 2006). TPACK combines Shulman's (1986) idea of pedagogical content knowledge with technology knowledge, which is essential for developing CS content knowledge in TCs.

By addressing these needs, we can better prepare new teachers who are skilled in both math and CS content knowledge, pedagogy, and technology as well-prepared early-career teachers of mathematics and CS. Early career teachers with a strong sense of self-efficacy are better educators (Abbitt, 2011; Scherer et al., 2017). Producing new teachers with high self-efficacy, content knowledge, and pedagogical confidence will help meet the growing demand for CS education. This paper reports on a three-year project integrating CS education teacher training into a mathematics teacher preparation program.

Purpose and significance of the study

The purpose of this study is to describe and analyze a pedagogical and curricular pathway for developing (1) a qualifying level of CS content knowledge and (2) TPACK and its knowledge sub-domains in TCs studying to be secondary mathematics teachers. The CS portion of the pathway in which the study reports on includes in addition to the requirements of secondary mathematics teacher preparation, two CS courses, a small field experience in a CS classroom, and a six-week, blended modules/discussion online Praxis II (5652) exam preparation set of modules. Our integrated approach to blend CS content, pedagogy, curriculum, and a field experience component is aimed at providing additional knowledge and skills to TCs beyond that of their secondary mathematics preparation program components (Gray et al., 2020; Odom-Bartel et al., 2021).

We use instruments with multiple sources of validity evidence. These instruments include: (1) a self-reported TPACK survey, (2) a performance assessment, (3) an observation protocol, (4) and standardized test score, to understand if the CS integration model is successful for participants without detriment to their pursuit of mathematics certification. In our sequenced and integrated approach to dually certify secondary mathematics TCs with a CS credential, we recognize that their knowledge and skills primarily stem from their secondary mathematics preparation program itself, exclusive of the CS preparation. Thus, we include a comparison group in our assessment of TPACK and performance, specifically to differentiate the participating mathematics TCs from their peers who did not participate in the CS preparation. Our aim is to understand if there are any positive/negative differences in TCs participating than those who did not. Furthermore, as a secondary analysis we include a comparison group for the Praxis II CS exam of inservice CS teachers who completed the same Praxis preparation materials as the TCs to understand the relationship of the CS preparation two-course integrated pathway.

Our analysis thus examines the validity and efficacy of a two-course CS integrated pathway and subsequent Praxis preparation blended instruction model to answer the following research questions:

1. What is the impact of the program's integrated pathway of courses and activities on secondary mathematics TCs' TPACK self-efficacy and CS content knowledge in being ready to teach CS?
2. Does TCs' TPACK self-efficacy strengthen because they also participate in the CS pathway compared to their non-participant peers?

3. By increasing coursework required to add-on a CS endorsement, what are the benefits or drawbacks to participant TC's development of TPACK and knowledge sub-domains compared to their non-participant peers?
4. What are the outcomes of the program's curricular experiences that help provide opportunity for secondary mathematics TCs in teaching CS in their future teaching careers?

Findings from this study will help improve the field's understanding of how mathematics teacher preparation programs can find nominal, yet rigorous, ways to integrate CS teacher preparation into existing programs. Gal-Ezer (1995) stated, "…since it is expected that not many CS academics [majors] will pursue a teaching career, the [preservice] program could serve academics from related fields (like mathematics…) who are interested in [teaching]" (p.164). Ultimately, it is rare for CS majors to consider teaching in K-12 as a career path, therefore it is urgently necessary to understand the effectiveness of models in the preparation of new teachers of mathematics to additionally be capable, if they choose, to teach CS.

Study framework

Our work is grounded in the TPACK theoretical framework, which is the knowledge integration of technology, pedagogy, and content domains in their respective disciplines (Mishra & Koehler, 2006, Figure 1). TPACK has gained wide attributions in both mathematics education (Niess et al., 2009; Voithofer & Nelson, 2021; Zelkowski et al., 2013) and CS education (Aktaş & Özmen, 2020; Zhu & Wang, 2023). TPACK expands on the framework by introducing technology knowledge (TK) into the conceptualization of pedagogical content knowledge (PCK) introduced by Shulman (1986). Shulman's presentation of the specialized knowledge that effective teachers possess requires strong core content knowledge (CK) and pedagogical knowledge (PK). That is, someone with strong content knowledge alone is likely not effective at teaching high school students, vis-à-vis someone with strong pedagogical knowledge alone cannot teach students well in a high school subject from which they have little content knowledge. Teachers must have both PK and CK. However, the most effective teachers are those who integrate both aspects and demonstrate strong PCK knowledge and practices as well. With the introduction of TK into the PCK framework, three additional domains of knowledge emerge, technological pedagogical knowledge (TPK), Technology content knowledge (TCK), and our specific area of interest in this study, technological pedagogical content knowledge (TPACK).

In mathematics education, TPACK has been widely accepted in the literature as a framework for the development of specialized knowledge in teacher professional development and teacher preparation (Handal et al., 2012; Hollebrands et al., 2016; McCulloch et al., 2018; Niess, 2005; Niess et al., 2009; Zelkowski, 2011b; Zelkowski et al., 2022a). In CS education, the trend seems very similar though the focus has been more heavily on inservice teachers of CS and elementary

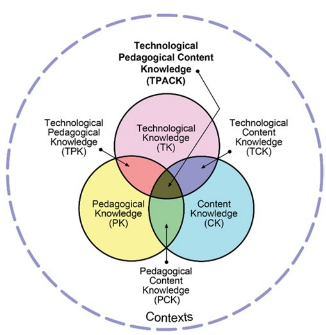

Figure 1. TPACK framework diagram.
Source: http://tpack.org.

TCs who are generalists, as opposed to secondary TCs (Giannakos et al., 2015; Gray et al., 2020; Mouza et al., 2017; Polly, 2014; Roussinos & Jimoyiannis, 2019; Schmidt et al., 2009; Štuikys et al., 2016). There have been scholarly trends upward to frame and study TPACK in teacher education for inservice and TCs in mathematics education and CS education. The TPACK model is not inactive or immobile when a teacher preparation program is focusing on CK development for CS and mathematics with TCs so measurement is challenging. Furthermore, isolating the effects of our CS education curricular pathway from that of the existing secondary mathematics preparation curriculum is challenging given the bidirectional relationships of knowledge domains of the TPACK framework (Cox & Graham, 2009).

Literature review

The construct of TPACK, requisite framework, how to measure it, and how to develop it has seen hundreds of studies published over the last two decades. We recognize the influential works in this section. We first describe relevant literature in developing TPACK in TCs (4.1). We then consider the literature as to promising methods of measuring TPACK with TCs (4.2). Lastly, we focus on the development of curriculum for use in producing CS CK in TCs (4.3).

Background to curricular design to develop TPACK components

For more than a decade, mathematics education teacher preparation programs have used various courses and experiences in efforts to develop TPACK in TCs (Kleiner et al., 2007; Leatham et al., 2008; Polly et al., 2010; Ronau et al., 2014; Zelkowski, 2011c; Zelkowski et al., 2022b, 2024a). Angeli and Valanides (2009) studied the development of TPACK capabilities in elementary TCs, while Zelkowski (2011c) replicated a similar study with a secondary mathematics teacher cohort. Both studies found similar changes in TCs' ability and technology implementation when peers engaged in making noticeable and explicit the connectedness between the technology tools, the lesson content topics, and teaching strategies. Literature suggests that integrating technology into Computer Science education can significantly enhance teaching strategies and the learning experience, particularly when there is a clear connection made between technology tools, lesson content, and teaching methodologies. Ultimately, we concluded the framework for our CS curricular development ought to mirror the approach in the mathematics education curricular pattern given past results in TPACK development. Further, we recognize our population of focus is TCs with varying levels of teaching experience in the secondary mathematics program. Some participants were in their last semester full-time student teaching internship, while others were just beginning their first of three sequenced methods teaching courses which are focused primarily on TCK, TPK, and TPACK development. Given this situation, the curricular design approach is one that relies on Niess et al. (2009), which proposed five levels of developmental progression in TPACK. These five levels include recognizing (knowledge), accepting (persuasion), adapting (decision), exploring (implementation), and advancing (confirmation). Our TC participants' TPACK development ranged from novice (prior to recognizing) through exploring (implementation). Due to the varying stages of the TCs' TPACK progressions while completing the CS pathway, we were challenged to rectify how learners at different TPACK levels of progression could all demonstrate TPACK growth.

With the challenge we faced, we relied heavily on using the role of more advanced TCs to lead with their peers in a community of practice (Wenger, 1999; Wenger et al., 2002). In a previous study (Gleason et al., 2017), the framework of a community of practice helped solidify the validation of an observation protocol for measuring student engagement and teacher facilitation during classroom instruction. In the current study, the community of practice guided CS curricular decision making. Communities of practice within teacher preparation programs provide a safe environment for TCs of differing knowledge levels to engage in learning activities with observations, interactions, and discussions with more advanced TC peers (Au, 2002; Warner & Hallman, 2017). We ultimately investigated the impact of this conceptual approach in the development of TPACK components within the CS curricular pathway.

Measuring TPACK components

Over the course of the last decade-plus since the emergence of the TPACK theoretical framework, researchers have used many avenues to study TPACK instructional approaches, curriculum, and outcomes. Early in the empirical TPACK study timeline, Koehler et al. (2012) presented five techniques that emerged in the literature: self-report surveys, performance assessments, open-ended questionnaires, interviews, and observations. Since their 2012 article, it would appear there has been continuing efforts to study TPACK both quantitatively (e.g. Joo et al., 2018) and qualitatively (e.g. Archambault, 2016). More recently, Akyuz (2018) developed and applied a performance assessment measure to mathematics TCs'lesson plans. In this 2018 study, Akyuz's performance assessment and parallel survey self-assessment yielded similar results of TPACK knowledge domains except for the pedagogy inclusive domains (i.e. PCK, TPK, TPACK). Despite the accumulation of empirical studies over the last decade-plus, what is clear in the literature, there is yet to be a field agreed upon instrument or method for measuring TPACK.

It has long been demonstrated that self-reporting self-efficacy and beliefs are a good predictor of teaching practices (Tschannen-Moran & Hoy, 2001), particularly with that of teaching mathematics (Ernest; 1989; Livers et al., 2020; Stipek et al., 2001). There has been little change in the literature about beliefs and practices, yet Abbitt (2011) presents a good argument that TCs have limited knowledge of their own capabilities to accurately assess their actual TPACK and ultimately what they will choose to do when teaching students in real classroom settings. Surveys with TCs do tend to tilt toward measuring confidence rather than knowledge (Graham et al., 2009; Lawless & Pellegrino, 2007; Schrader & Lawless, 2004) while Voogt et al. (2013) and Akyuz (2018) posit that TPACK assessment needs to include additional measures of actual performance by TCs. Moreover, there have been research findings that indicate isolating the TPK, TCK, and PCK domains, particularly with that of TCs, given that they are highly correlated and the knowledge boundaries so blurred (Angeli & Valanides, 2009; Archambault & Barnett, 2010; Chai et al., 2011; Cox & Graham, 2009; Graham, 2011; Scherer et al., 2017; Zelkowski et al., 2013). When considering this literature and synthesizing the results, one could conclude that CK, TK, PK, and TPACK are essentially the more accurately measured knowledge domains in TCs as opposed to practicing teachers with years of classroom experience. In our study, we recognize these aspects from the literature, as well as to include additional measures of performance.

Curriculum for developing Computer Science CK, PK, TK, and TPACK

Advanced Placement (AP) Computer Science Principles (CSP) is *an introductory college-level computing course that introduces students to the breadth of the field of Computer Science* (College Board, 2020). The curriculum framework for AP CSP focuses on developing students' ability to learn how to design and evaluate solutions that can be applied in CS (Zelkowski et al., 2022b). These solutions are developed through algorithms and programming; thus, expanding the students' understanding of computing innovations, computing systems, and their impact. The framework for CSP is designed to be accessible to all students, regardless of their prior experience in CS. The framework emphasizes computational thinking and problem-solving, as well as the social and ethical implications of computing. The framework is organized around five big ideas (College Board, 2020):

1. **Creative Development**: The importance of collaboration in developing computing innovations is highlighted in this concept.

2. **Data**: The storage of information in binary and its translation into a visible or audible form.
3. **Algorithms and Programming**: The importance of determining the efficiency of algorithms and implementing them in a program.
4. **Computer Systems and Networks**: The impact of dividing tasks across multiple computing devices on the speed of processes; how information is transmitted on the Internet and the measures in place to prevent system breakdowns.
5. **Impact of Computing**: The societal impacts of computational solutions and the ethical concerns that arise with their creation.

Methods

The major objectives of this quasi-experimental designed study (Shadish & Luellen, 2012) were, with the use of measures with validity evidence and standardized scores, to understand the impact and effectiveness of a CS teaching credential being integrated into a secondary mathematics teacher preparation program centered on the development of TPACK (mathematics) in TCs. Simultaneously, we were injecting CS content knowledge development into the mathematics teacher preparation program without compromising the development of TCs' initial certification needs in mathematics while aiming for growth in CS content knowledge and TK requisite for teaching CSP and potentially additional CS courses.

Participants

The participants of this study were secondary mathematics TCs ($N = 29$) who elected to participate in a federally funded grant project to support their interests in adding on a CS teaching endorsement to their secondary mathematics teacher preparation program. All mathematics TCs completed a 100-level CS course equivalent to the high school AP course, Computer Science Principles (CSP). The grant provided the resources and support to develop a second advanced curriculum and methods content course (400-level) from a teacher's knowledge perspective on AP CSP. Three separate cohorts ($N = 10$, 10, 9 respectively) completed the two-course CSP sequence, while 15 of the 29 participants completed the CS Praxis II exam.

Development of the study treatment(s)

After the TCs completed the initial CSP content course, (immersion of CSP content knowledge) they enrolled in a curriculum and methods of teaching CSP framework course (See Figure 2). The goal of the second course was to reflectively look at the CSP course through a detailed examination of the CSP Curriculum Framework and the Create Performance Tasks outlined by the College Board as a K-12 teacher would need to do. In essence, after gaining a foundation of content knowledge in CSP, the second course (curriculum and methods) provides an opportunity for TCs to learn more about the motivating reasons behind the inclusion of topics in the CSP curriculum, increase their depth of knowledge of the CSP curriculum, how to develop sample lesson plans for several of the learning objectives of CSP with a perspective on equity and inclusiveness and examine the AP CSP Curriculum Framework as it relates to state and national standards (connecting pedagogical knowledge).

Instrumentation measures

The TPACK instrument was selected for its specific development for secondary mathematics TCs and provides a proficient instrument to measure TK, PK, CK (math), and TPACK in the

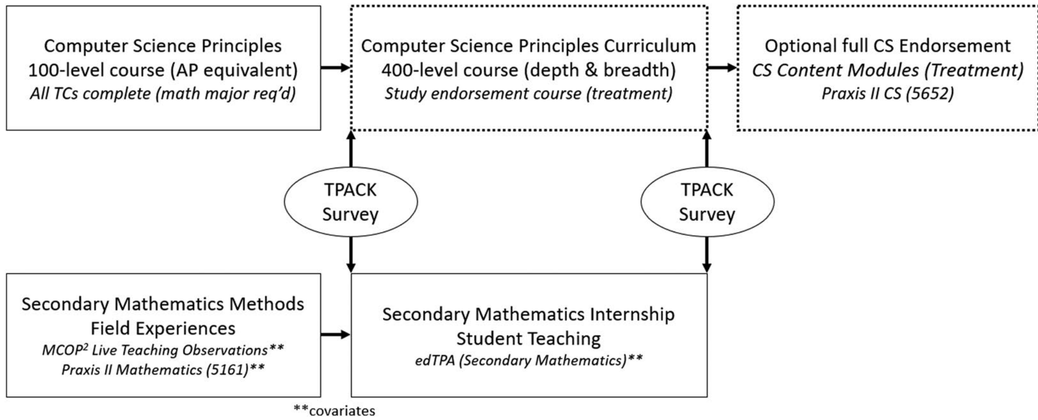

Figure 2. Study design map.
Note: Dotted boxes represent the study treatment(s) for earning a CSP and/or full CS endorsement. Solid boxes represent the concurrent coursework all secondary math TCs complete.

U.S. (Zelkowski et al., 2013). This instrument has been widely cited, translated into other languages, and appears to be the lone instrument designed for TPACK U.S. secondary mathematics TCs with multiple sources of validity evidence (AERA, APA, & NCME, 2014). The TPACK instrument was administered in a pre-post timing on the second course of the two-course sequence to understand the effects of the 400-level CS course since all TCs complete the 100-level CS course as part of their preparation program coursework whether participants or not (See Figure 2).

The Computer Science Praxis II (5652) exam is a standardized CK (CS) exam given by the Education Testing Service (ETS) in which a rigorous validation process includes expert panels, revisions, and field work for test content. Furthermore, cut score panels and explicit use interpretations provide validity evidence for consequences of testing. Lastly, response processes on tested items provide the final evident source of validity evidence. ETS provides additional internal analyses on alternate forms, test-retest, and sensitivity analysis regarding reliability of the test (ETS, 2014; Kane et al., 2017). The Praxis II was completed by 15 participants at the conclusion of the summer online modules focused on CS CK development.

Controlling covariate variables

In an effort to control for TCs' academic ability in the analyses, many covariates were available for analyses. For certification program completers, the Mathematics Classroom Observation Protocol for Practices [MCOP^2] (Gleason et al., 2017) provides a national observation protocol with multiple sources of validity evidence that measures overall teaching performance during live instruction. It measures a teacher's ability to enact teaching practices and support student engagement. The instrument provides a strong measure of PCK evidence in TCs during formally observed, full lesson planning and enactment. The MCOP^2 observation data was collected in the semester prior to TCs being full time student teaching interns (i.e. their final semester before graduation). The mathematics Praxis II (5161) is a standardized measure of CK (math) validated using the same process as the CS Praxis II exam discussed above. Lastly, the edTPA (SCALE, 2020) is a national teaching portfolio measure of first-year teaching readiness and pedagogical ability, including multiple sources of validity evidence. Combined, these three measures allow for a strong cadre of academic ability and teaching performance to isolate as a control and compare participant TCs to their peers who did not participate. For all TCs who did not complete the certification program, we did not have these three covariates in completion. Therefore, we collected the ACT composite and ACT mathematics scores of the participants as a proxy for prior achievement. ACT scores were collected on certification program completers and non-completers for the analyses.

Comparison groups

The participants in this study were enrolled in a secondary mathematics teacher preparation program. Teacher candidates who participated in the CS dual certification pathway self-selected to participate and very well may just be "better academic" students that would take on the additional challenge. The TCs who self-selected not to participate in the CS opportunity serve as the comparison group to participants. A second comparison group of inservice teachers completed *only* the Praxis II modules and did not complete the two-course CS course sequence. The second group provides a comparison in terms of the effects of the two-course sequence on the CS Praxis II. Both comparison groups provide a stronger analysis for demonstrating the impact on TPACK (math) self-efficacy and CS CK with the study's CS curricular sequence design for making inferences.

Analyses of the data

To understand the development of CS CK in participants, the Praxis II (interval) serves as the nationally standardized and validated measure to analyze. The 15 TC participants are compared using an independent samples t-test to the group of 16 inservice CS teachers who completed the Praxis II prep modules concurrently to try to qualify for a teaching add-on CS teaching credential *via* the Praxis II testing pathway. T-test assumptions of normal distributions with Shapiro-Wilk (p-value > 0.05) and Levene's check for homogeneity of variances ($p > 0.05$) were met in the two independent samples. Without prior achievement marks of the inservice teachers, there are no options to use controlling covariates. Moreover, the participants who did not take the CS Praxis II and their peers who did not participate in the project two-course sequence serve as a group to forecast through a multiple regression model to understand the impact of participation through the use of the covariates. Lastly, to understand the development of TPACK (math) among participants, two analyses were conducted with the first being a simple pre-post dependent paired t-test with the TK, CK (math), PK, and TPACK (math) domains. The second analysis considers the covariates in analyzing the TPACK (math) factor scores with an ANCOVA of participants and non-participants. Again, Shapiro-Wilk & Levene are provided and were met in all groups for each variable with only TK post scores by non-participants slightly beyond normal distribution, this is presented in the appropriate table and confirmed by a non-parametric test of significance.

Results

Over the course of the three years of our study and project, approximately two-thirds of secondary mathematics TCs (29 of 45) self-selected to participate in the two-course sequence AP CSP 100- and 400-level courses. Of the 29 participants, 15 elected to move into the CS Praxis II modules preparation. Of the other 14 non-Praxis participant TCs, five did not finish the teacher preparation program for various reasons, while nine finished the teacher preparation program. Our results are organized in the following order: (1) the CK (CS) comparisons between TCs and inservice teachers who completed the CS Praxis II exam, (2) the TPACK (math) pre-post ratings of participant TCs and non-participant TCs in the same secondary mathematics teacher preparation program, and (3) the analyses of outcomes by controlling for prior achievement.

Computer Science content knowledge

Table 1 presents the descriptive statistics of the 16 participant inservice teachers who completed the online preparation modules followed by the CS Praxis II exam, and further provides the statistics for the 15 TCs as a measure of CS content knowledge.

Table 1. Praxis II (CS CK) Computer Science test results.

Group	Mean Score	Std. Dev.	Std. Error	Min.	Max.	95% Conf. Int. Lower Bound	95% Conf. Int. Upper Bound
Inservice	162.625	24.679	6.170	126	198	149.475	175.776
TCs	172.667	19.212	4.960	145	200	162.023	183.306

Note: The independent samples t-test produced an F-statistic = 1.544 and p-value of 0.218 (*ns*). The 95% confidence interval of the mean difference was (-26.3, 6.2). Possible scores range from 100-200.

The TCs outscored the inservice teachers by a little more than 10 test points. The Praxis II Computer Science test reports about 6 points as the standard error, thus we interpret this difference as almost 1.5 standard error units higher. Given the smaller sample size of each group, the t-test did not report a statistically significant difference, reporting a p-value of 0.218 (*ns*). While we initially hypothesized the 10-point difference would be statistically significant after the means were computed from the participants, ultimately our initial hypothesis was incorrect. However, we can report with confidence that the passing rate for the six-week modules resulted in a 100% rate if completed fully by an inservice teacher or TC. The only non-passing Praxis II scores were from participants who did not complete all of the modules in preparation for the test. The national average on this exam was 165–166 during the study data collection period in which TCs scored a standard error higher, and inservice teachers scoring about half a standard error lower (see Table 1).

TPACK results

In this section, we present a number of TPACK (math) analyses. First, we present the results from the TC participants only. Second, we then do a comparison between the participants and their peer non-participants. Third, we add in the TC cohorts prior to this project to the non-participant group in an effort to balance group sizes and re-run the analyses. Lastly, we control for ability across groups by utilizing covariates in post-hoc analyses.

Participant TPACK results

Table 2 demonstrates the results of the four-TPACK (math) factors given at the onset of the first CS course and near the conclusion of the second CS course. The results demonstrate statistically significant differences pre-post on all four factors. These results demonstrate that participants believed their self-evaluation of their knowledge on all four factors increased when completing the two-course CS sequence. The CK factor measures mathematics content knowledge and is not of significance to this study. However, it does present the opening previously discussed, to make an effort to compare these results to those of non-participant peers who completed their mathematics, mathematics methods courses, and classroom field experiences during the same period. The TPACK survey was administered to non-participant peers during the project period in their mathematics methods courses in the same weeks. The results are presented in 6.2.2. Please see Zelkowski et al. (2013) for factor score computations with each item's coefficients. Here, we report the range of possible TPACK component scores based on the coefficients as follows:

TK[4.030, 20.150] CK[2.058, 10.290] PK[2.453, 12.265] TPACK[3.189, 15.945]

TPACK comparisons between participants and non-participants

The results are presented in Table 3 for the TPACK instrument for non-participants in the same secondary mathematics teacher preparation program. When examining the pre-post scores *via* a paired samples t-test, TK, PK, and TPACK were significant improvements. CK (math) increased but not with statistical significance.

Table 2. TPACK (math) pre-post results for participants.

Factor	**Pre-score**	Std. Dev.	Std. Error	**Post-score**	Std. Dev.	Std. Error	t	*Sig. p*-value
TK	**14.187**	2.072	0.385	**16.340**	2.170	0.403	5.200	*0.000*
CK	**8.768**	0.912	0.169	**9.330**	1.049	0.195	2.905	*0.007*
PK	**9.375**	1.417	0.263	**10.220**	1.442	0.268	3.525	*0.001*
TPACK	**12.333**	1.769	0.329	**13.745**	1.933	0.359	6.037	*0.000*

Note: CK refers to mathematical content knowledge on the TPACK survey. All pre-post analyses show $p < 0.05$ significance for the $N = 29$ participant teacher candidates. Shapiro-Wilk tests for normality of differences was met, p-values were all > 0.10 as well as Levene's equality of variance >0.05.

Table 3. TPACK pre-post results for non-participants.

Factor	**Pre-score**	Std. Dev.	Std. Error	**Post-score**	Std. Dev.	Std. Error	t	*Sig. p-value*
TK	**13.941**	2.882	0.672	**15.774**	1.895	0.473	3.180	*0.006*
CK	**8.893**	0.832	0.208	**9.315**	0.981	0.245	2.056	*0.058*
PK	**8.616**	1.749	0.435	**10.002**	1.133	0.283	3.523	*0.003*
TPACK	**8.763**	2.453	0.563	**11.880**	1.541	0.385	6.980	*0.000*

Note: CK refers to mathematical content knowledge on the TPACK survey. All pre-post analyses show $p < 0.05$ significance for the $N = 16$ non-participant teacher candidates except on CK. Shapiro-Wilk tests for normality of differences were met for CK, PK, and TPACK, p-values were all > 0.10, while TK was not normal based on the post-scores only. A Wilcoxon non-parametric test confirmed the TK pre-post difference was significant for non-participants.

Table 4. TPACK pre-post comparison of participants and non-participants growth.

Factor	***Pre-score* Non-Part.**	***Pre-score Part.***	Pre-diff.	**Post-score Non-Part.**	***Post-score Part.***	Post-diff.	Non-Part. Growth	Part. Growth
TK	**13.941**	***14.187***	0.246	**15.774**	***16.340***	0.566	1.833	2.153
CK	**8.893**	***8.768***	−0.125	**9.315**	***9.330***	0.015	0.422	0.562
PK	**8.616**	***9.375***	0.759	**10.002**	***10.220***	0.218	1.386	0.845
TPACK	**8.763**	***12.333***	3.570	**11.880**	***13.745***	0.385	3.117	1.412

Note: CK refers to mathematical content knowledge on the TPACK survey. Levene's test for equality of variances produced p-values > 0.10 when comparing groups meeting the assumption. Similarly, Wilk-Shapiro confirmed p-values > 0.10 for normality.

Next, when testing for mean differences between pre-scores on TK, CK (math), PK, and TPACK, only the TPACK factor pre-score was statistically different between participants and non-participants (t-test p-values respectively, 0.742, 0.653, 0.120, 0.000). Therefore, the results indicate there is no difference between the participant and non-participant groups on TK, CK (math), and PK at the onset of starting the two-course sequence. However, we recognize the pre-score differences in TPACK of about 3.5-points. We address this in the discussion section. Testing for the mean differences on the post-scores, we found the two groups differed on TK, not so on CK (math) and PK, and still so on TPACK (t-test p-values respectively, 0.014, 0.963, 0.605, 0.002). Ultimately, we see the participant group grew more than their peers on TK (2.2 v. 1.8) to produce a post-score mean-difference. This is discussed when comparing the two groups and their final TPACK component scores.

TPACK comparisons of the participants and non-participants with covariates

In Table 4, we highlight some of the differences between groups to set up the discussions and interpretation of the findings. We note that the participant group had self-reported TK, PK, and TPACK scores higher than their non-participant peers, where non-participants indicated a higher, but a small difference in relation to CK (math). At the conclusion of the two-course sequence, the participant group had higher scores on all four factors. We observed participants' growth was higher for TK and CK factors, while non-participants showed more growth in PK and TPACK factors. This is addressed later in the discussion.

Although our analyses and findings point toward growth across both participants and non-participants, we were quick to focus on whether the results were based on a stronger or weaker group of TCs who elected to participate or not. We accessed our three covariates for those who completed the teacher certification program. Tables 2–4 represent all TCs who were enrolled in the CS two-course pathway and certification program while completing the TPACK pre-post survey. Not all participants and non-participants completed their initial teacher certification program. Therefore, the Praxis II, MCOP², and edTPA scores were not available on all of the 29 participant TCs and 16 non-participant TCs. Participants with all three covariate scores drop the group sizes to 21 and 12, respectively. Table 5 presents the results of the comparisons of the certification program completers with three covariate scores. Next, Table 6 presents the same analyses while using the ACT composite and mathematics scores. The use of the ACT as the lone covariate resulted in 25 participants and 16 non-participants for the same analyses. There were some differences addressed in the discussion.

We interpret Tables 5 and 6 with our ANCOVA results being addressed by considering first, if Levene's Test of Equality was met. In each ANCOVA, the p-values and related significance all exceeded 0.10 and met the assumption. Second, one should examine if the covariate significantly adjusts the associate between the two groups and the outcome measured factor. Third, one should examine if the outcome (TPACK factor) is statistically significant. If the covariate is significant but not the outcome factor, then the ANCOVA provides evidence the covariate does not adjust the association. On the other hand, if the covariate is non-significant and the outcome is significant, then the covariate does not adjust the association between the groups and outcome variable. But, when the covariate and outcome are both significant, one can

Table 5. TPACK pre-post ANCOVA comparisons for certification program completers.

Factor	Pre-score Non-Part.	Pre-score Part.	*Pre-diff.*	F-Stat	Post-score Non-Part.	Post-score Part.	*Post-diff.*	F-stat
TK	13.430	13.716	*0.286*	0.025	14.900	15.693	*0.793*	0.026
Praxis II								
CK	8.870	8.719	*−0.151*	0.311	9.372	9.144	*−0.228*	0.010
Praxis II								
PK	8.260	9.160	*0.900*	1.084	9.819	10.022	*0.203*	0.088
Praxis II			***	15.800				
TPACK	8.284	12.121	*3.837***	12.537	11.945	13.540	*1.595*	1.501
Praxis II			**	9.286				

Note: CK refers to mathematical content knowledge on the TPACK survey. Participant group size $N = 21$. Non-participant group size $N = 12$. Levene's test for equality of variances produced p-values > 0.05 meeting the assumption.
***Denotes $p < 0.001$, **$p < 0.01$, *$p < 0.05$ in the table.
MCOP² and edTPA did not significantly adjust the association between the predictor and outcome variable on any of the TPACK factors pre- and post- so they are not included in the table. The Praxis II math exam did show significant adjustments to the PK and TPACK factors at the start (pre-).

Table 6. TPACK pre-post ANCOVA comparisons of the two-course sequence.

Factor	Pre-score Non-Part.	Pre-score Part.	*Pre-diff.*	F-Stat	Post-score Non-Part.	Post-score Part.	*Post-diff.*	F-stat
TK	13.941	13.953	*0.012*	0.480	14.686	16.148	*1.462**	6.831
ACT-c			*	6.043				3.267
ACT-m				3.564				3.979
CK	8.893	8.761	*−0.132*	0.002	9.315	9.269	*−0.047*	0.005
ACT-c				2.782				0.702
ACT-m			*	4.854				1.625
PK	8.616	9.324	*0.708**	4.808	10.002	10.146	*0.144*	0.316
ACT-c			*	4.849				0.757
ACT-m				0.590				0.415
TPACK	8.763	12.304	*3.541****	33.311	11.880	13.694	*1.814***	10.554
ACT-c				1.419				0.721
ACT-m				0.245				0.241

Note: CK refers to mathematical content knowledge on the TPACK survey. Participant (Part.) group size $N = 25$. Non-participant (NP) group size $N = 16$. Levene's test of equality of variances p-values >0.10 meeting the assumption.
***Denotes $p < 0.001$, **$p < 0.01$, *$p < 0.05$ in the table.
The ACT composite (c) and math (m) score did show significant adjustments to the TK, CK, and PK factors at the start (pre-) but not at completion of the two-course sequence (post-).

interpret that the adjustment of the covariate still results in evidence of group differences on the outcome.

Discussion

We structure the discussion section in five parts to answer our two research questions. The first three sections (7.1–7.3) address the first research question, while the last two sections (7.4–7.5) address the second research question. First, we discuss our interpretations of the CS content knowledge outcome when comparing TC participants and inservice teacher participants. Second, we discuss the participants themselves and their growth in TPACK and the subcomponents as measured. Third, we discuss the comparisons of the participants to their peers. Last, we close with reflections on the CS certification integration followed by implications for teacher preparation programs and the design to dually certify TCs with a CS add-on.

Content knowledge in Computer Science

During this project, 15 of the participant TCs self-selected to move beyond the two-course sequence preparing their readiness to teach Advanced Placement (AP) Computer Science Principles (CSP). These 15 TCs spent about six weeks completing online modules to study and prepare for the CS Praxis II exam. At the same time, 16 inservice teachers from around the region also engaged in the same online modules. The inservice teachers (ISTs) in all instances were already teaching CS courses in secondary schools. The results indicated that both groups were not statistically different in their group mean scores, though we recognized some differences to discuss.

The TCs' mean group score was 10 points higher (see Table 1). In examining the national statistics on the Praxis II CS exam (#5162) during this project period, the TC mean was seven points above the national median (165) while the inservice teachers' (ISTs) mean was three points below the national median. The 25th and 75th percentiles nationally were 149 (the passing score for the state) and 186, respectively. Examining the individual level scores, we found 6/16 ISTs and 1/15 TCs scoring in the first quartile which are considered failing scores. Also, we found 4/16 ISTs and 4/15 TCs scoring in the upper-most quartile. Lastly, 6/16 ISTs and 10/15 TCs scored in the two middle quartiles, the interquartile range of 149 to 186. We wondered if passing the test alone was significantly different, but a Pearson Chi-Square test resulted in a p-value of 0.083, which is debatable as to being significant in such a small sample size as it is significant using 0.10 for a 90% confidence level.

Ultimately, our interpretation is that TCs were more likely to pass the CS Praxis exam. We believe the higher mean and higher success rate is due to two factors. The first, TCs completed the AP CSP two-course preparation sequence prior to the Praxis II modules. Secondly, ISTs were full time teachers during the year and likely not typical in using six weeks in the summer for professional development (module completion time). We believe the module completion time is the indicator, as TCs spent more time in hours in the modules during the six weeks and all TCs but one (the failing score) fully completed the modules. If we assume the Praxis II is a solid measure of CS content knowledge (CK) and valid measure of such, then our findings indicate the development of entry level CS CK to begin teaching CS courses should include all three phases (two-course sequence and CS CK modules) since 25% of the ISTs failed the Praxis II. We would also recommend that more than six weeks be available for ISTs to complete the modules.

TPACK development during the two-course CSP sequence

In this project, 29 participants completed the two-course sequence focusing on the readiness of understanding the curriculum and content of the AP CSP high school course. Although some individuals performed much higher than others, collectively, the participants all show statistically significant higher self-ratings on TK, CK (math), PK, and TPACK factors pre-post (Table 2). Therefore, we interpret these results that the participants benefited in building self-efficacy on all TPACK components we measured as readiness for teaching AP CSP embedded into a secondary mathematics teacher preparation program. Of the 29 participants, 22 TCs entered the profession teaching mathematics and/or CS, two TCs did not earn a teaching credential but graduated with another degree and are teaching under an emergency teaching certificate, and five TCs changed majors to something other than teaching. Ultimately, we believe our results indicate that a good preparation model for adding-on AP CSP endorsement (course teaching permit only) and those who did the Praxis (full CS licensed endorsement) is an effective model when the primary program (Secondary Math) has a solid and strong history of a high-quality preparation program (Zelkowski et al., 2024a, 2024b; Zelkowski & Campbell, 2020).

TPACK comparisons between participant TCs and non-participants TCs

The secondary mathematics teacher preparation program at The University of Alabama has a long record of using measures with multiple sources of validity evidence with strong outcomes, including an appropriate attrition rate of under-qualified or under-prepared TCs (Gleason et al., 2015, 2017; Zelkowski et al., 2013, 2018, 2022c, 2024b; Zelkowski & Gleason, 2016, 2018). Thus, we expected there to be some differences in comparing the CS project TCs and their peers who did not elect to participate. We theorized initially that those who elected to participate did so because they were more confident and/or stronger academically and/or sought the stipend our grant provided. We also theorized that there may be little difference in the TPACK measures between groups.

Without considering covariates to control for prior academic ability, Table 3 shows similar results for the non-participant TCs. They demonstrated significant growth on the TK, PK, and TPACK factors, but not so on the CK (math) compared to participant peers. We then looked at Table 4 and observed that based on raw factor scores, participants grew more on the TK and CK (math) factors, while the non-participants grew more on the PK and TPACK factors. We wondered during the analyses if this pointed toward non-participants as more likely to have not participated in the CS add-on credential opportunity because they had lower self-efficacy on teaching and teaching with technology. Certainly, that contention is probable given that the non-participant group had much lower means on TPACK and PK on the pre-survey indicating more room for growth. The ANCOVA tests in Tables 5 and 6 confirm that for program completers (those who earned a teaching license) and of the two-course sequence participants and non-participants, when controlling for program internal measures (Table 5) and prior achievement (ACT, Table 6) we find our contention to be supported. That is, the TCs who completed the certification program had significantly higher PK and TPACK scores even when adjusted based on the Praxis II math scores demonstrated during the program. However, by the end of the two-course sequence, all of the TPACK scores were not significantly different between groups (Table 5) when controlling for program performance.

When considering all TCs who participated in the two-course sequence and their non-participant peers while controlling for prior achievement with the ACT, we found what we interpret to be our strongest results to discuss. In Table 6 on the post-scores between groups, the TK and TPACK factors are significantly higher for participants while the CK (math) and PK factors were not. When considering the 25 (of 29) TC participants with ACT scores, as well as the 16 TC non-participants, we see that on the pre-survey, the ACT-composite score did adjust the PK measure and still had a significant difference between groups. Thus, we conclude the non-participant TCs certainly had less confidence in PK which could be a reason for nonparticipation. However, the PK factor score differences were erased on the post-survey. Our strongest findings were on the growth in self-efficacy on the TK and TPACK factors for participants even when controlling for all covariates accessible. We conclude, the CSP two-course sequence significantly increases TK so much for TC participants that they soared ahead of their peers as a result of participating. Secondly, even though the non-participants aggregately grew more on TPACK, TPACK remained significantly higher for participants. We conclude that the secondary mathematics teacher preparation does well on the CK (math) and PK factors to increase self-efficacy of TCs to where the two-course CSP sequence had negligible results on CK (math) and PK. However, we cannot conclude the same for the TK factor in which participation clearly showed much higher growth. Regardless of participation or not, TCs reported growing their TPACK. Non-participant TCs were unable to catch their participant TC peers.

Reflections on the preparation pathway design

The immersion of CS content knowledge was expected to be a key to a successful project. TCs had an extended time learning, evaluating, and incorporating Computer Science concepts into their education preparation program (Odom-Bartel et al., 2021) by participating in a semester-long AP CSP course while also taking other educational prep courses. A benefit of requiring the TCs to take a full AP CSP course at the beginning of the pathway was that they were able to incorporate many of the computational thinking and CS principles into their other educational preparation portfolios within their preparation program (Kong et al., 2020; Zelkowski et al., 2024a). In contrast, the traditional approach to training inservice teachers about AP CSP is usually relegated to a single week-long summer training, with little time for teachers to develop their own understanding of CS concepts, specifically the need to have time to learn how to program and code. Participants who completed the program reported feeling more prepared to teach and have been able to apply what they learned in the CS courses to their teaching (Odom-Bartel et al., 2021).

Having TCs already coming in with backgrounds of pedagogical knowledge through their current educational preparation programs allowed the project team to use the existing structure to build bridges between mathematics education pedagogical knowledge and CS pedagogical knowledge. Effective teaching starts with an understanding of how students learn. Teachers who possess pedagogical knowledge have a deeper understanding of how students learn, which enables them to design instruction that is more effective and meaningful (Guerriero, 2017). In developing the methods course we used these key elements of pedagogical content knowledge (Shulman, 1986):

Knowledge of representation of subject matter

- Using interactive cloud-based posting boards, students built a repository of learned and adapted knowledge of CS concepts. Checkpoints were built in to examine levels of understanding using this repository.
- Discussions were created to help build understanding and adaptation of CS concepts into teaching. Each checkpoint was used as a way to reassess understanding and revisit concepts that were still unknown.
- Readings and discussions were assigned surrounding an equitable lens in a CS classroom. Techniques such as scaffolding, scaling, flexible and adaptive activities were examined.
- TCs were required to build their own lessons using these techniques. These lessons were then peer-reviewed and discussed for strengths and weaknesses. Ultimately, the goal was to develop a repository of sound lesson plans that a first-year teacher would be able to use in their classroom.

Curriculum knowledge

- Classroom observations were assigned to help TCs experience ways in which to situate the CS content in the classroom environment.

- Different curriculum packages were examined with the idea that TCs could build content specifically geared toward their own students and school environment. TCs reviewed nationally available lesson plans under a critical lens and shared them with their peers.

Knowledge of educational context

- TCs learned about state and local standards and how they intersected with the AP CSP framework.

Knowledge of the purpose of education

- We stressed the importance of continued growth in CS knowledge by providing additional PD pathways to continue their educational development in CS by exposing TCs to local, state, and national CS education organizations (Cochran et al., 1993).

Technology knowledge

- TCs were required to create mock programs using the same requirements as their students; that is, the TCs submitted assignments that were the same as the AP CSP Create Performance Task that their future students would need to complete. This allowed TCs to not only be creative in how they manipulated the content but gave a much-needed perspective of the content.

General implications for CS teacher preparation program models

We believe these strong results using instruments with multiple sources of validity evidence indicate that the two-course sequence is a reasonable and effective preparation for teaching the stand-alone AP CSP course. With the TK and TPACK factors showing such strong results, we believe that TCs built the CS knowledge and TPACK confidence required for teaching the AP CSP course alongside their secondary mathematics primary teaching discipline. Programs can look for ways to integrate two CS courses by first examining the general program electives and/or program requirements. For secondary mathematics, the mathematics major requires an introductory CS course that was revised to become the equivalent of the AP CSP course at the college level with some educational components in the course. The deep-dive AP CSP curriculum course at the upper level (senior/post-bac) was truly the only additional course for participants compared to non-participants. With sound advising during the freshman and sophomore years, we found it would be easy to fit the second course into the junior year for most TCs making sure they did not over-do-it with general electives in their first two college years. We also found it possible for TCs to complete the course during full-time student teaching internships given the outcomes presented here. We offered the course at 5:00pm one night a week (Monday) to allow the interns the ability to finish up their field experience teaching in a local K-12 school and attend the class on campus.

The CS Praxis II preparation modules were not a course for credit, but rather an online paced curriculum to prepare for the exam. We can see value in making this an asynchronous class for course credit if that would benefit TCs somehow in their programs of study. When grant stipends are not available, we believe course credit would need to be the incentive for completion as the Praxis II preparation is ultimately a CS content knowledge building experience over six weeks which TCs spent on average 120 h completing the modules. The modules build knowledge in CS domains that are not present in the two-course sequence but certainly needed in teaching CS courses beyond that of AP CSP. We believe that the modules course can be completed in 6-8 wk effectively, thus opening the door to have the course be a summer course or interim term for credit. We certainly believe that for TCs, completing all six modules results in a near certainty of passing the Praxis II exam as the only TC to not pass did not complete all modules and scored just four points from passing.

Limitations

While this project and study provide significant findings in some places and non-significant findings in others, there are limitations for consideration in this quasi-experimental designed study where participants were not randomly assigned to groups (Shadish et al., 2002). The differences in TPACK and sub-component scores reported here, could be a result of TCs' different academic histories, ability, regression to the mean, and self-development (Marsden & Torgerson, 2012). While the covariates available were used to make an attempt to control for such differences, it is certainly within the realm of possibility for explaining some of the statistical differences in the findings and may hide statistical significance in other places. Secondly, we acknowledge the self-selection of participants into the treatment(s). Self-selection certainly could explain some of the variance, differences, and non-significant results in the outcomes.

Implications: Future expansions to all secondary teaching disciplines

Our three-year project with secondary mathematics TCs revealed opportunity and results for dually certifying in mathematics and CS. Given such results, our project looked to expand to other secondary teaching disciplines and beyond our own institution. A new project was conceived and funded by The National Science Foundation (Project #2122882). The project is open to TCs in secondary English, Social Studies, Science, and Mathematics to add-on CS teaching credentials. Our team has collaborated to include TCs from six additional partner universities in our region where their TCs can complete the two-course sequence for an add-on AP CSP endorsement to their own institutional primary certification program, and if they choose, advance and prepare for the full CS add-on teaching credential *via* the Praxis II

We believe this model demonstrates positive results and has ultimately led to mathematics teachers welcoming the practice of also teaching CS as early career teachers. One graduate from the first study cohort stated in her exit interview,

> If I hadn't been given the opportunities this past year with CS, I don't know where I would be today. Having this CS background helped me get a job at a once-in-a-lifetime school and I could not be more thankful! So far, I have really enjoyed teaching CS [in addition to math]. I teach the non-AP version of CSP at my school [first year teaching], and so I felt very comfortable going into the course with my prior knowledge. While there are things that I still struggle with (like pacing), I think my kids are learning a lot and exploring the subject along with me. We do labs almost every week and I try to add in some CS unplugged projects every once in a while to keep them engaged. Everything I've used so far I've gotten from the AP Summer Institute or from the [CS 400-level course] course last spring. (Odom-Bartel et al., 2021, p. 163)

She concluded by presenting nationally alongside the authors by saying, "teaching CSP has allowed me to learn more about what student Mathematical Practices look like in real applications of the mathematics I teach. It has improved my ideas about the NCTM Mathematical Teaching Practices". She has now become a lead trainer in the state for CSP inservice teacher training as a third-year teacher. The results of life-long professional impact on TCs in this project are targeted in the expansion project to all secondary teaching disciplines across seven higher education teacher preparation programs.

Disclosure statement

The author(s) are not aware of any conflicts of interest.

Notes on contributors

Jeremy Zelkowski is an associate professor in the secondary mathematics education teacher education programs at The University of Alabama. He has served as the program coordinator for 15 years. Part of his research is situated in the quality of teacher education program design in relation to outcomes, as well as the importance of using internal program measures with multiple sources of validity evidence. The integration of Computer Science certification as an add-on for secondary teachers has been an ongoing project for six years. He has led programmatic transformational change at UA for secondary mathematics teacher education and within the national Mathematics Teacher Education Partnership. He has served in numerous service leadership roles across multiple professional organizations.

Rebecca Odom-Bartel (Becky) is an assistant professor in the College of Education and Public Affairs, Teacher Education department. Her research focuses on Computer Science Education. She is a graduate of the University of Alabama and has spent the last eight years working to advance computer science education in K-12 and college level settings. Her experience is both in college classrooms and secondary education classrooms teaching programming, web-design, CS methods, and robotics. Becky's research is tied closely to her passion for CS education and has worked on multiple NSF CS4ALL and DOE EIR grants focusing on building pathways for pre-service and in-service teachers to become confident and strong CS teachers. Additionally, Becky works closely with several organizations and educational institutions to assist in the development of equitable and inclusive methods of teaching and sharing CS curriculum to high school and college students.

Dr. Jeff Gray is a professor of computer science at the University of Alabama and is a national leader in computer science education, and is a member of Code.org's Education Advisory Council. With several National Science Foundation grants, Gray has worked with the College Board and Google to craft a new Advanced Placement computer-science course designed to increase secondary and post-secondary educational interest in computer science and improve collegiate preparation for STEM awareness. Gray also works to train high school teachers to integrate computer science into technology courses and teach the upcoming new AP computer science course. He hosts an annual Alabama Robotics Competition for middle and high school students along with summer computer camps for similarly aged students.

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