Examining Relationships Among Aspects of Secondary Teachers' Potential Competence and Instructional Characteristics

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Within secondary mathematics teacher preparation, recent scholarship points to the efficacy of strong links between university mathematics course content and secondary mathematics teaching practice. Studies aligned with this view typically focus on overarching course design, rather than instructional characteristics. This investigation builds on a prior such study that found improvements in teachers' potential competence for teaching across four different content areas. In the present study, we analyze 137 teachers' expectation for success in and valuing of core instructional practices and their gains in content knowledge for teaching, as well as a purposive sample of videos from 6 courses enrolling a subset of these teachers. Based on our analysis, we suggest that different aspects of university instruction may have differential influence on attitudinal and cognitive aspects of teachers' potential competence. Moreover, instructional practices that most benefit attitudinal aspects may be in tension with those that most benefit cognitive aspects.

Keywords: teaching practice, secondary mathematics teacher education, competence

For decades, the narrative of secondary mathematics education was one of disconnect. Klein (1924/1932, as cited in Kilpatrick, 2019) lamented a "discontinuity" between undergraduate mathematics experiences and secondary teaching. Empirical findings documented that many secondary teachers found their undergraduate mathematics courses irrelevant to their teaching (Goulding et al., 2003; Zazkis & Leikin, 2010). There is recent promise in an approach to designing mathematics courses for prospective secondary mathematics teachers that connects undergraduate course mathematics *content* to secondary mathematics *teaching practice* (see Lai et al., in press and Wasserman et al., 2023 for reviews). These results conclude that curricular materials that intentionally promote such connections beneficially serve prospective secondary mathematics teachers (PSMTs). However, these studies lack an investigation of the undergraduate pedagogy through which the intended curricula are enacted. Yet different enactments of the same curriculum may have differential impacts (Remillard, 2018).

Our purpose is to hypothesize teaching practices that may impact PSMTs' development of competence for teaching. We operationalize competence in terms of expectation for success and valuing of evidence-based teaching practices, and the development of content knowledge for teaching. In doing so, we account for relationships among these traits. We address: (RQ1) *To what degree do attitudinal and cognitive aspects of competence associate?* (RQ2) *What aspects of evidence-based teaching practice may most influence PSMTs' development of attitudinal and cognitive aspects of competence for teaching?* We analyzed teaching practices with the Mathematics Classroom Observation Protocol for Practices (MCOPP; Gleason et al., 2017) applied to a purposive sample of 6 instructors' videos. Hence, we contribute an analysis of relationships between PSMTs' development of competence and instructional practices they experienced.

Terminology. In this study, *secondary* refers to Grades 6-12, though we note that 90% of participants intended to teach Grades 9-12. *PSMT* refers to prospective secondary mathematics teachers, *instructor* refers to an undergraduate instructor, and *student* refers to a secondary student. *Content* refers to mathematics and statistics.

Conceptual Perspective

We take competence for teaching to include teachers' capacity to harness knowledge and attitudinal traits (Blömeke et al., 2015). With respect to knowledge, we focus here on *content knowledge for teaching* (*CKT)*, defined as disciplinary knowledge entailed in the recurrent work of teaching mathematics or statistics (Ball et al., 2008; Baumert et al., 2010; Thompson & Thompson, 1996). With respect to attitudinal traits, we focus on expectancy and value for enacting evidence-based teaching practices. A person's *expectancy* is their expectation of success at carrying out a task in a particular situation (Wigfield & Eccles, 2000). *Value* is the importance of carrying out a task well, and can encompass utility, enjoyment, and personal fulfillment (see Eccles & Wigfield, 2020, for a review). We use evidence-based teaching practices to refer to teaching practices that promote discussion and elicit student thinking about content in ways rooted in disciplinary norms (e.g., Gleason et al., 2017; Grossman et al., 2009). Such teaching practices are associated with instructional quality and student learning outcomes at the secondary levels (e.g., Baumert et al., 2010).

Competence is influenced by socialization (Eccles & Wigfield, 2020), and PSMTs' socialization includes their experiences in the mathematics courses they take (e.g., Buchholtz & Kaiser, 2013; Werler & Tahirsylaj, 2022). In this study, all participating PSMTs enrolled in courses using written curricula developed by the Mathematics Of Doing, Understanding, Learning and Educating for Secondary Schools (MODULE(S2)) project, which promoted explicit links between university course content and secondary mathematics teaching practice. We posit that even with this similarity across PSMTs' experiences, there may still be differences due to instructors' enactment of the written curriculum (Remillard, 2018).

One theme in studies of undergraduate mathematics instruction in the past decade has been the effectiveness of *evidence-based teaching practices*, particularly those consistent with inquiry-based mathematics education (Laursen & Rasmussen, 2019; Freeman et al., 2014). We operationalize the term "evidence-based teaching practices" as teaching for conceptual understanding, including opportunities to examine mathematical structure, through teacher interactions and students' engagement. One characterization of evidence-based teaching practices (among others) is represented by the Mathematics Classroom Observation Protocol for Practices (MCOPP), which has been validated to capture the presence of evidence-based practices in undergraduate mathematics instruction (Gleason et al., 2017). The principles behind MCOPP items are consistent with guidance at the elementary, secondary, and undergraduate levels for mathematics teaching (e.g., Mathematical Association of America, 2018; National Council of Teachers of Mathematics, 2014). Gleason et al. (2017) reported that MCOPP items fall into two dimensions: Teacher Facilitation and Student Engagement.

Background

Evaluation of effectiveness in instruction is typically conceptualized in a process-product paradigm: "the search for relations between classroom processes (instruction) and products (what students learn" (Gage & Needels, 1989, p. 254). For instance, one of the main results cited in support of evidence-based practices in undergraduate mathematics education is Freeman et al.'s (2014) meta-analysis. They concluded from their analysis of 225 studies that "active learning" pedagogies (process) increase undergraduates' scores on concept inventories and course examinations (product) in STEM fields. Indeed, the term "evidence-based practices" is rooted in this paradigm: they are teaching practices for which process-product research indicates positive impacts on student outcomes.

Studies assessing the impact of evidence-based teaching practices as a process tend to focus on one product at a time. For instance, Laursen et al. (2014) examined the impact of inquiry-based methods on undergraduates' assessments of their own learning gains. Johnson et el. (2020) investigated the effect of active learning methods on undergraduates' knowledge of group theory. Freeman et al. (2014) focused on outcomes in course examinations and concept inventories. These results do not account for the possibility that particular teaching practices may have differential impacts on different aspects of student outcomes, such as attitudinal in comparison to cognitive outcomes.

Although process-product studies of inquiry-based mathematics education have included mathematics courses for PSMTs in their data, their analyses typically consider PSMTs' experiences in aggregate with undergraduate mathematics students more generally (e.g., Laursen, et al., 2014). However, PSMTs have needs distinct from other undergraduate mathematics students, because content knowledge for teaching is different from content as needed in other mathematically-intensive careers (e.g., Krauss et al., 2008; Hill et al., 2007). Moreover, although prior studies in undergraduate mathematics education have examined undergraduates' attitudes toward mathematics, they have not addressed attitudes specific to future teaching practice.

This study addresses the gap in examining the potential for differential impacts as well as the need for studies specific to PSMTs. We analyze a combination of teaching practices experienced by PSMTs in a mathematics course, content knowledge for teaching, as well as expectancy and value for carrying out evidence-based teaching practices.

Data & Method

The context for this study is the MODULE(S2) project, a research and development effort that produced written curricular materials in algebra, geometry, mathematical modeling, and statistics. Materials for each content area are intended to span one term of a university mathematics course for PSMTs. All materials featured opportunities for PSMTs to apply course content to teaching situations such as responding to student ideas. In a previous study, the MODULE(S2) project examined pre- and post-term data for PSMTs' expectancy and value for enacting evidence-based teaching practices, and their CKT. This research found mean increases in PSMTs' outcomes across each of these constructs (Lai et al., 2023). Further, this prior study indicated that PSMTs noticed their instructors' enactment of evidence-based practices. One significant limitation of this prior study is that it examined instruction indirectly, using PSMTs' perception of the instruction they experienced.

There are two parts to the present study. For RQ1, we examined the association among PSMTs' gains in expectancy, value, and content knowledge for teaching. For RQ2, we compared ratings for videos of 6 instructors' use of evidence-based practices to mean gains of participating PSMTs enrolled in their courses. Our rationale was that if we were going to examine the impact of instructional practices on PSMTs' development of three different traits (expectancy, value, and content knowledge for teaching), we should also examine the relationship among these constructs in the population. If significantly associated, instructional processes influencing one trait may influence others in a similar way. If association is more limited, we may be looking for differences in the influence of instructional practices on traits.

Participants for RQ1 were 137 PSMTs enrolled in university courses using MODULE(S2) materials, with 50 in algebra, 25 in geometry, 16 in mathematical modeling, and 46 in statistics. For RQ2, we purposively sampled 6 instructors' courses in geometry and statistics, the areas with the most video data available for analysis. Following the process-product model, we posited that PSMTs' mean gains in CKT represented variation in instruction. Our purposive sample consisted of videos from instructors with high and low relative mean gains among participating PSMTs, resulting in a selection of 19 videos from 4 geometry instructors' courses (12 videos; mean CKT gains ranged from 10% to 19.50% of the maximum possible CKT score) and 2 statistics instructors' courses (7 videos; CKT gains 10.6% and 26.88%). Video lengths ranged from 40 minutes to 75 minutes and documented a single class period instruction.

As for instrumentation, we measured pre-/post-term expectancy and value for carrying out evidence-based practices using a Likert-item survey, whose phrasings were drawn from Wigfield and Eccles (2000). In the prior study, internal reliability (Cronbach's α) was $\alpha = 0.91$ for the expectancy assessment, and $\alpha = 0.79$ for the value assessment. A common guideline for Cronbach's α is to consider values over 0.7 as acceptable and values over 0.9 as excellent (Nunnally, 1978). We measured (CKT) in each area with instruments featuring applications of the specified content to teaching (see Lai et al., 2023 for more details on instrument validity for capturing PSMTs' CKT). We analyzed instructional videos using MCOPP, which consists of 20 items describing aspects of two categories: undergraduate student engagement (SE) (e.g., assessing strategies, communicating ideas to peers) and teacher facilitation (TF) (e.g., allows for wait time; encourages independent thinking) (Gleason et al., 2017). Each item is rated on a scale of 1 to 3, representing less to more intense enactment.

For RQ1, the first three authors analyzed relationships between PSMTs' expectancy, value, and CKT. To do so, we used Pearson's correlation coefficient r to measure effect size of correlations. We used p-values to determine if there is evidence of a non-zero correlation in the theoretical population, but focus on practical significance.

For RQ2, four researchers (including the fifth and sixth authors) coded videos with MCOPP items, reconciling in pairs any difficult evaluations. We intended to analyze relationships between these dimensions, items, and mean PSMT gains per course in expectancy, value, and CKT. We decided to focus solely on TF as the videos often followed the instructor, affording limited data on student engagement. Of note, after 2017, items addressing equitable teaching practices were added to MCOPP from outside the original factor analysis. Based on parallelism in phrasing, we posited how these items fell into the teacher facilitation dimension; we call this dimension *TF+*.

Here we emphasize the phrasing of RQ2: "What aspects of evidence-based teaching practice <u>may</u> most influence PSMTs' development of attitudinal and cognitive aspects of competence for teaching?" Although we use Pearson's correlation coefficient r in this analysis, we do so in an exploratory way. Our findings are potential hypotheses. We posited that $r \sim 0$ ($\sim 0.1 < r < \sim 0.1$) can be interpreted as the hypothesis that the MCOPP item or dimension has little relationship to the PSMT gain in the trait (expectancy, value, or CKT). Otherwise, positive r indicates a hypothesis that the teaching practices described in the MCOPP item or dimension benefits PSMTs' development in that trait. And negative r indicates a hypothesis that those teaching practices may have less benefit for PSMTs' development.

We also emphasize the study context: we already know that PSMTs on average gained expectancy, value, and CKT. Thus a negative correlation indicates that the dimension may have had less impact on the PSMTs' development than others for the specified trait, rather than indicating that the dimension is detrimental to the PSMTs' development.

Results

RQ1: PSMTs' Gains in CKT Versus Expectancy or Value Show Mostly Statistically Insignificant Correlations with Negligible Effects

The first three authors used Pearson's correlation coefficient *r* to analyze relationships between PSMTs' gains in CKT versus their gains in expectation to implement and valuation of core instructional practices. Each PSMT's scores on these metrics were first converted to a percent change from pre to post out of total possible points on the relevant assessment or survey. Figure 1 shows Pearson's correlation coefficient *r* and the p-values for this group of PSMTs, both partitioned by content area and as a whole group. Note that both results for the combined group were statistically significant with $p < 0.05$, though their *r* values were small. The only content-specific significant result was for statistics and value, with a higher *r* value of +0.41. These results imply that, for the most part, PSMTs' learning of mathematics content for teaching was separate from their expectation and valuation of core instructional practices.

	CKT vs. E *r* value	CKT vs. E p-value	CKT vs. V *r* value	CKT vs. V p-value
Algebra	+0.107	0.458	+0.022	0.882
Geometry	+0.137	0.514	+0.153	0.466
Modeling	+0.342	0.195	+0.336	0.203
Statistics	+0.188	0.212	+0.41	0.005
All Content Areas Combined	+0.168	0.0497	+0.199	0.019

Figure 1. Pearson's correlation coefficient r and the p-value for correlations between PSMT's gains in content knowledge for teaching (CKT) and gains in expectancy (E) or value (V). Statistically significant results are highlighted in green.

RQ2: We Hypothesize that the Process as a Whole (of Evidence-Based Practices) is the Sum of Parts in Tension

Overall, Pearson's correlation coefficients with the TF dimension with expectancy, value, and CKT ranged from 0.022 to +0.49. Our estimate for standard error over the 19 observations (for 19 videos) is 0.45 assuming independent observations. This assumption is necessary for the analysis even though these observations are not independent, with multiple videos originating from the same instructor. Nonetheless, we infer that these coefficients are relatively small. The exceptions are the correlations with gains in expectancy, which were +0.45 (TF) and +0.49 (TF+).

When examining correlation for individual MCOPP items with expectancy, value, and CKT, we find wider variation. With expectancy, r ranged from -0.12 to +0.73. With value, r ranged from 0.42 to 0.57 actual. With CKT, r ranged from -0.62 to +0.51. For some items with larger relative r in terms of absolute value (operationalized as $|r| > \sim 0.4$), the sign for the coefficient flipped between expectancy and CKT, or between value and CKT, or the coefficient for CKT was relatively small (for examples, see Figure 2).

	7) The teacher promoted modeling with math.	11) The teacher's talk encouraged student thinking	13) There was a climate of respect for what others had to say	14) In general, the teacher provided wait-time
E	-0.08	+0.18	+0.58	+0.73
V	-0.42	+0.42	+0.57	+0.56
CKT	+0.51	-0.62	-0.09	+0.01

Figure 2. Examples of largest correlation coefficients (in absolute value) obtained among MCOPP items and PSMTs' change in expectancy (E), value (V), and content knowledge for teaching (CKT)

Discussion

We examined pre/post-gains in PSMTs' expectancy, value, and CKT as well as instruction experienced by the PSMTs, for which our analysis found insignificant correlations between PSMTs' gains in these aspects. We also hypothesized that teacher facilitation would have the greatest additional impact on PSMTs' gains in expectancy, in the context that we know students on average experienced gains across each trait across all courses.

Our study was limited in several ways. The band of CKT gains that determined the purposive sampling was relatively narrow, limiting differences to detect. The videos coded, though purposively selected, may not represent the widest variation in instruction; the courses with the highest and lowest mean CKT gains in a content area sometimes had no video data available. Additionally, we completed coding in two of the four original content areas. For this reason, we view our results as hypotheses for further consideration.

One hypothesis we make is that in the presence of gains in competence, teaching practices may make more difference in expectancy for carrying out evidence-based teaching practices than other traits. One reason for this being that experiencing evidence-based teaching can foster confidence by providing a model for what such teaching looks and feels like.

We also hypothesize that different teaching practices have differential benefits to distinct intended outcomes for competence (gains in expectancy, value, and CKT). Here we distinguish teaching practice, conceived as the whole of a teacher's instruction, from teaching practices, conceived as routines and aspects within instruction (Lampert, 2010). Further, in any given moment, an instructor can only focus on so many individual practices; emphasizing one practice may necessitate doing so at the expense of another. How do we conceive of "effective" teaching practices when faced with these kinds of results? Perhaps effective teaching practice is composed of teaching practices in tension.

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