SELF-EFFICACY AND THE KERNEL OF CONTENT KNOWLEDGE

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In this study, when mathematics teachers were provided professional development pertaining to physics, their physics content knowledge improved, as did their self-efficacy in teaching mathematics through physics. This analysis reveals how these two improvements interacted and how that interaction changed over time. Also, this study examines what components of self-efficacy were influenced. These results have practical significance for STEM professional development design and implementation, while revealing theoretically significant nuances in the development of teacher knowledge. Intriguingly, self-efficacy gains were correlated with content knowledge gains, but only in the content knowledge that was retained over a longer period of time, suggesting that teachers' content knowledge may have a kernel, or core, that is more correlated with affects and beliefs, such as self-efficacy.

Keywords: Teacher Knowledge, Beliefs

Studies suggest that integrated approaches to teaching STEM (Johnson, 2013; NRC 2002), weaving together science, technology, engineering, and/or mathematics, improves student achievement (Becker & Park, 2011), reflects the nature of STEM professions (Wang et al., 2011), enables deeper understanding (NRC, 2012), and highlights mathematical relevance (GAIMME, 2016). However, integration of insular disciplines brings new needs to teacher education because the diverse knowledge needed to teach integrated STEM is not prevalent in the teacher workforce (Roehrig et al, 2012). Although both the American Academy of the Arts and Sciences (Pallas, Neumann, & Campbell, 2017), and the National Academy of Sciences (2012) recommend creating teaching resources for the integration of STEM disciplines, new resources are insufficient by themselves. Professional development (PD) providers should strive to equip practicing teachers with the content knowledge (CK) and self-efficacy (SE) to effectively teach integrated STEM content.

Teachers' SE (Bandura, 1997) has been shown to correlate with teachers' CK (Swackhamer, 2009), but how might this correlation differ in an area outside a teacher's specialization, such as physics CK with math teachers? In this study, we examine PD that supports physics-based and inquiry-based math teaching, by analyzing teachers' CK and SE. Data from 20 in-service math teachers informs the following questions, for both "short term" (after a 1-week summer workshop) and "long term" (after 4 monthly post-workshop meetings):

1. Based on pre-post data, does inquiry-based PD influence CK about physics-based math, or SE for teaching math through physics, or components thereof?
2. Do pre-post differences in these CK and SE variables correlate with each other?

Theoretical Perspectives

SE pertains to certainty about one's abilities (Bandura, 1997). While some studies have linked teachers' SE to students' achievement and motivation (Caprara, et al., 2006; Skaalvik & Skaalvik, 2007), longitudinal studies have revealed that correlations between teaching SE and instructional quality are not purely causal or consequential (Holzburger, Philipp, & Kunter, 2013). Although some studies have found that continued and objective-focused PD improves SE (Brinkerhoff, 2006), little research has indicated how PD influences teachers' SE in a subject outside their expertise. Examining effectiveness of inquiry-based PD, prior research shows mixed results, sometimes improving and sometimes worsening SE for teaching science (Avery & Meyer, 2012). Few instruments measure SE

In: Sacristán, A.I., Cortés-Zavala, J.C. & Ruiz-Arias, P.M. (Eds.). (2020). *Mathematics Education Across Cultures: Proceedings of the 42nd Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, Mexico. Cinvestav / AMIUTEM / PME-NA. https:/doi.org/10.51272/pmena.42.2020

for teaching math and science in an integrated way. Mobley's (2015) SE for teaching integrated STEM uses a 3-factor model, with a *social* factor, including motivating students, a *personal* factor, including developing new knowledge, and a *material* factor relating to access to tools.

With Common Core came an emphasis on mathematical modeling (CCSS, SMP). However, many practicing teachers had minimal training in mathematical modeling and in the sciences that utilize modeling. While many teacher training programs adapted to include more modeling coursework, PD remained essential for practicing teachers. This landscape accentuates the importance of studies such as this, in which math teachers are supported in the learning of physics or other STEM content. In this study, CK was measured by multiple-choice items similar to math questions found on a physics Advanced Placement test. We consider CK to be similar to Shulman's (1986) *subject matter content knowledge*, and because of the interdisciplinary nature of this study, is related to Ball's (1993) *horizon knowledge*, which implies awareness of how math content spans the curriculum. Considering subdomains of subject matter knowledge (Ball, Thames, & Phelps, 2008), we suspect these subdomains may interact differently with non-cognitive variables, such as affect and belief, and may persist differently over time.

Methods

Professional Development Workshop

The grant-funded workshop, titled *Let's Get Physical! Teaching Mathematics through the Lens of Physics*, included 32.5 hours over 5 consecutive summer days, followed by 4 monthly 1-hour meetings during the following fall semester. The inquiry-based PD highlighted the themes: (a) integration of math and physics and (b) student motivation.

The grant provided each teacher's school with physics lab equipment, including Vernier physics packages, Logger Pro software, spring kits, current probes, circuit boards, refraction blocks, lasers, track systems, and iPads. During days 1-4, the teachers completed 2-3 physics experiments each day and discussed pedagogical topics related to student motivation. On day 5, a mathematics and physics panel of faculty and graduate students made presentations about applied topics and current research. During the 4 follow-up meetings, conducted through video-conferencing, the participating teachers shared lesson ideas and experiences with one another.

The physics labs in the workshop, available online (Author2 & Author1, 2017), were inquiry-based and aligned to standards in middle school math, Algebra I & II, and geometry. In one lab, teachers modeled the behavior of live insects to learn about displacement, velocity, and geometry. In another, teachers dropped coffee filters and modeled their fall to learn about drag, logarithms, and graphical methods. Other labs involved basketballs, toy cars, lasers, and circuits.

Participants and Recruitment

University faculty and administrators from local schools recruited applicants through meetings and emails. Teachers of middle school math, Algebra I & II, and geometry were encouraged to apply. Twenty math teachers, from 5 school systems, were selected. Most held bachelor's degrees in mathematics, 14 held graduate degrees in education, 2 held master's degrees in mathematics, and 2 held master's degrees in physics. Six participants were male, and 14 were female. Because administrators participated in recruitment, more teachers with leadership qualities may have been more likely to apply. Because this workshop was marketed as *Let's Get Physical! Teaching Mathematics through the Lens of Physics*, teachers with more interest and knowledge in physics may have been more likely to apply.

Data Collection and Analysis

Using instruments described in Table 1, data was collected from 20 in-service teachers before and after the week-long summer workshop, and also after 4 monthly post-workshop meetings.

Table 1: Descriptions of Instruments

Construct	Length	Scale	Cronbach Alpha
Self-Efficacy (SE)	8 items	0 = *Certainly I am not capable.* 10 = *Certainly I am capable.*	.96
Content Knowledge (CK)	5 items	0 = incorrect, 1 = correct	.59

We framed the SE inventory using Mobley's (2015) 3 factors - social, personal, and material. Per Bandura's (2006) advice for maintaining content validity, all items were phrased as capability statements, and caution was taken to avoid confusion with self-worth or locus of control. Also, to refine our instrument, we piloted it at a STEM education conference.

Items for the *social* sub-scale of SE say, *I am capable of…*

- leading my students in conducting physics labs in such an effective way that all of my students are motivated to learn math.
- anticipating and preventing likely student errors while conducting physics labs.
- coordinating a superior cross-curricular math lesson with a science teacher at my school.

Items for the *personal* sub-scale of SE say, *I am capable of…*

- making meaningful connections between physics and mathematical concepts.
- revising a physics lesson plan to make it appropriate for my mathematics classroom.
- responding immediately if a student asks me how a math homework problem is related to physics.

Items for the *material* sub-scale of SE say, *I am capable of…*

- finding related physics-based examples, no matter what mathematical concept I am planning to teach.
- teaching students to use technology and equipment to do physics labs, without technical difficulties.

We used paired *t*-tests to detect significantly non-zero pre-to-post differences, and we used regression analysis to determine statistically significant correlations between those differences.

Results

CK in physics-based mathematics improved over the course of the 1-week workshop. Post-test CK scores (M=3.20, SD=1.28) exceeded pre-test scores (M=1.70, SD=1.30). However, some of this acquired CK was impermanent. Four months later, when re-tested, the gains in CK (M=2.37, SD=1.64) were no longer significantly different from pre-test scores. See Table 2.

Table 2: Overview of Results

Research Question	After 1-Week Workshop	After 4 Monthly Meetings
Did the PD influence CK?	$t(19)=4.94^*$	$t(18)=1.79$
Did the PD influence SE?	$t(19)=6.10^*$	$t(18)=5.57^*$
Did CK and SE gains correlate?	$r(18)=.022$	$r(17)=.515^*$

*Significant at the .05 level

Regarding SE, however, the benefits did not fade. The teachers showed significant improvement in SE, both in the short-term and in the long-term. Short-term (M=6.69, SD=1.79) and long-term (M=6.91, SD=2.00) post-workshop SE ratings significantly exceeded those pre-workshop (M=4.46, SD=2.06), and also significantly improved in each SE subscale.

Regression analysis was used to test if the gains in SE or its subscales significantly correlated with participants' content knowledge gains. In the short-term, gains in CK and SE were not significantly correlated, and none of the SE subscale gains significantly correlated with CK. However, in the long-term, CK and SE gains did correlate, $r(17)=.515$. For 2 SE sub-scales, the correlation was significant as well. See Table 3.

Table 3: Correlation Tests in Gains after 4 Monthly Post-Workshop Meetings

	correlation with CK gains
self-efficacy (SE) gains	$r(17)=.515$*
SE *social* subscale gains	$r(17)=.514$*
SE *personal* subscale gains	$r(17)=.511$*
SE *material* subscale gains	$r(17)=.374$

*Correlation is significant at the .05 level.

Discussion

The *Improving Teacher Quality* (ITQ) grant program from the U.S. Department of Education, which provided the funding for this PD project, has been de-funded at the federal level. In the face of funding limitations, local and state education agencies are planning various strategies for supporting STEM education. With integrated STEM initiatives, teachers are more frequently expected to collaborate across disciplines and teach content peripheral to their areas of expertise. As math curricula adapt to ever-changing technology, the need for cross-disciplinary PD will increase, and integration of math with computer science, biology, engineering, and data science should be deliberately implemented, with effects on both short-term and long-term CK and SE gains examined. This study suggests that as future PD is provided, implementing an inquiry-based approach will improve the overall effectiveness of these supports. In addition, PD should attend to personal, material, and social concerns about teaching mathematics.

When future studies examine correlations between CK gains and SE gains, the findings of this study should be considered in research design. Our results suggest that short-term studies may not reveal connections that would be apparent in longer-term studies. Future theoretical research about types of CK should also consider changes over time. Because our short-term CK and SE gains were not correlated, but our long-term gains were, we suspect that there was a kernel, or core, of CK that persisted longer, and that this CK kernel was more likely to have influenced teaching practice, since it was correlated to pedagogical SE. Also, one might suspect that teachers who chose to use certain physics-based lessons in their classes in the fall might have retained certain parts of CK, and thus, teaching practice might be influencing both SE and CK. Thus, instead of viewing CK as a substance that can be acquired and then retained, this study substantiates a more complex model of knowledge, one in which teachers participate in a process of using their content knowledge, reminiscent of Sfard’s (1998) participation-acquisition framework. Future studies should examine how teaching practice influences CK, and how teachers decide to use inquiry-based lessons in math classes.

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