Teachers as Learners:  
A Model to Build Teacher Content Knowledge through Engineering Design

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Background

Difficulties attracting students to STEM careers are enhanced in Appalachia and West Virginia (WV), where the national average in percentage of STEM degrees (21% vs. 30%). 17% of adults over 25 in WV have a Bachelor’s degree (lowest nationwide); many communities have much lower rates. Thirteen of 55 WV counties are “low education counties” where “25 percent or more of residents 25-64 years old had neither a high school diploma nor GED.”

Teachers Engaged in STEM and Literacy (TESAL) is a three year Math Science Partnership providing proximal context for developing the model described here. Structurally, TESAL involved two phases of professional development each summer, two days each semester, and classroom observations/support (see Figure 1). Participating teachers remained in the program all three years and created then implemented and refined two lesson plans per year. TESAL involved teachers from four counties with 41% to 67% low-income students, less than 80% highly qualified teachers in mathematics or science, and below average mathematics and science test scores in a state well below the national average.

The 24 participating teachers had 3 to 22 years teaching experience (mean = 8 years) and considered themselves science educators (n=11), mathematics educators (n=8), special educators teaching math or science (n=4), or technology educators (n=1). All participants had a bachelor degree; 17% (6) were highly qualified per federal definitions.

TESAL Model

Our model utilized iterative design/redesign to address “the engineering problem” of building teacher content knowledge (see Figure 2). We identified knowledge gaps, engaged teachers as learners in design tasks requiring that knowledge, and developed the learners’ design tasks to further support teacher learning, and required teachers to apply the model with their students. The full paper describes a concrete application of this model focused on middle school physical science and related mathematics standards.

Diagnostic Teacher Assessments in Mathematics and Science (DTAMS) revealed struggle with mathematics requiring analysis, reasoning, and application and two areas related to Next Generation Science Standards. We focus here on: Real World Newtonian Physics (MK-P2-2) Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and the mass of the object.) 12/24 teachers incorrectly identified relative motion of dropped object and how to consider friction forces.

Two Force Concept Inventory (FCI) items (see Table 1) were used to uncover misconceptions related to gravitation, specifically “gravity intrinsic to mass,” “heavier objects fall faster,” “gravity increases as objects fall,” and “gravity acts after impetus or grows” misconceptions notoriously difficult to change.

Table 1 displays means, standard deviations, significance, and effect size statistics from paired samples t-tests. There was a medium-large significant improvement (0.49 to 0.33, p<0.05, d=0.22) on the FCI on the second item, a medium small non-significant improvement (0.34 to 0.39, p=0.05, d=0.41) on the second item, and no improvement on the third. The first two items are most similar in context to the ramps and marbles modules as they involve questions about speed or acceleration of metal balls of the same size but different weight and a stone, respectively, being dropped from a roof. The third item requires respondents to identify forces acting as a ball moves through a frictionless channel, requiring transfer to a substantially different context than that provided by the ramps and marbles modules. One iteration of our model remediated a stubborn misconception in a specific context. We will focus future iterations on transferring that learning more broadly.

Discussion

End of summer focus groups discussed impact on teachers and students, impact on teaching practice, and challenges. A compelling issue across focus group themes was productive struggle—in particular, that of teachers—seen in their comments about themselves, student effects, and parent responses. TESAL teachers are experiencing productive struggle authentically, and their misconceptions are similar to those of their students. Design based learning provided an experimental framework that was familiar to them and enabled further richer experimentation that was targeted at understanding misconceptions and could be adapted for use in their classrooms.

Productive struggle is a key feature in learning that is conceptual, robust, and transferable. Yet it is difficult to understand and implement. Part of that difficulty is the dominant cultural view of mathematics and science as only for “some people” or as a static body of knowledge that must be learned rather than created. Productive struggle hinges on instructional tasks that investigate content and create knowledge in meaningful ways. Therefore, instructional approaches that engage students in productive struggle also challenge existing notions of what it means to do mathematics and science; this can be uncontrollable for parents, other teachers, administrators, and some students. Making these experiences and related difficulties explicit may support teachers developing understanding of how to effectively engage their students in productive struggle.

Valid and reliable assessment of teacher content knowledge coupled with available content expertise of project personnel is a strength that gives rise to a challenge in determining how to address and scaffold content needs of prospective groups. How much do middle school mathematics teachers need to know about science, and how much do science teachers need to know about mathematics, in order for them to meaningfully plan integrated instruction? In the context of somewhat low content knowledge scores and specific content deficiencies, especially outside of teachers’ primary content area, how do we address content needs in safe and authentic ways? Many teachers are uncomfortable opening their content knowledge gaps to remediation. We found sustained engagement with our teachers critical, and teachers were more open to remediating gaps in the context of design projects focused on similar gaps their students are likely to have; gaps that just happen to overlap with content knowledge teachers need to develop more deeply themselves.

Table 1: Force Concept Inventory (FCI) items pre/post means (standard deviations), significance level (p), and effect size (Cohen’s d).

<table>
<thead>
<tr>
<th>FCI Item</th>
<th>Pretest</th>
<th>Posttest</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two metal balls are... dropped from the roof...</td>
<td>.53 (.52)</td>
<td>.93 (.26)</td>
<td>.01 .77</td>
<td></td>
</tr>
<tr>
<td>A stone dropped from the roof...</td>
<td>.33 (.49)</td>
<td>.53 (.52)</td>
<td>.19 .41</td>
<td></td>
</tr>
<tr>
<td>A ball is shot at high speed into the channel...</td>
<td>.07 (.26)</td>
<td>.00 (.00)</td>
<td>.33 .27</td>
<td></td>
</tr>
</tbody>
</table>

Note: Two-tailed significance from paired samples t-test; n=15 as not all teachers were present for both pretest and posttest.

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