Developing a Tool to Investigate Teacher-Candidates' Pedagogical Content Knowledge in a Technology-Based Physics Methods Course

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This research was supported in part by a grant from the UBC Teaching and Learning Enhancement Fund.

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Abstract

A centerpiece of teacher education is the development of teacher-candidates' Pedagogical Content Knowledge (PCK), which underpins their decision-making. PCK is affected by the use of modern technologies. Consequently, it is necessary to understand the impact of modern technologies, such as electronic-response systems (clickers), on teacher-candidates' PCK. Benefits of clicker-enhanced pedagogy in large undergraduate courses are well documented. They include increased student participation, reduced anxiety, continuous formative assessment, and enhanced conceptual understanding. However, these benefits are relatively unexplored in small classrooms. This paper reports on the implementation of clicker-enhanced pedagogy in a small physics methods course and describes the development and implementation of a tool aimed at assessing its impact on teacher-candidates' PCK. Reflections on its successes and challenges are discussed.

Keywords: STEM teacher education, pedagogical content knowledge, electronic-response systems, conceptual science learning

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Introduction

Technology is ingrained in today’s society, and raising technology-literate students is dependent on having technology-literate teachers in schools. The possibilities for technological tools are endless, leaving educators with more options than they could ever integrate into their classrooms. With this excess of options, the responsibility falls on teachers to understand more than the basics of technology but also the pedagogical impacts it can have on their students. This is particularly important in science, technology, engineering and mathematics (STEM) courses, where technological tools are central to STEM careers.

In the early 80s, a number of conceptual multiple-choice physics tests were developed that were able to reliably and consistently measure student conceptual understanding of basic physics principles (Halloun & Hestenes, 1985a, 1985b; Hestenes, Wells, & Swackhamer, 1992; Maloney, O’Kuma, Hieggelke, & Heuvelen, 2001). These tests were easy to administer and thousands of undergraduate students in introductory physics courses have undergone these assessments. To the surprise of faculty members and educational researchers, it was found that in traditional (teacher-centered) introductory physics courses students’ conceptual understanding improves very little. Moreover, conceptual physics understanding does not necessarily correlate with students’ ability to solve end-of-chapter problems, or with their liking or disliking a course instructor (Hake, 1998). According to Hake’s study, student conceptual gains were dismal in the courses where the instructors lectured most of the time and did not actively involve students in learning. These findings, however, are supported by the studies on active learning and student engagement conducted by educational psychologists in the last century (Bonwell & Sutherland, 1996; Svinicki, 1998, 2004).

About the same time, Prof. Eric Mazur at Harvard University introduced a new pedagogy, called Peer Instruction (Mazur, 1997b). The focus of this pedagogy was on engaging students during large lectures through polling them on conceptual physics questions relevant to the topics discussed in class. Initially he used multiple-choice conceptual physics questions he designed and letter cards (A, B, C, D, and E) distributed to every student for polling. Peer Instruction pedagogy, coupled with measuring student conceptual understanding using the instruments described above, allowed him to begin measuring the effect of this active engagement pedagogy on student learning. In the 1990s, Mazur replaced low-tech letter cards with a high-tech electronic response system that included a clicker for every student and allowed Mazur to display the histogram of student responses to conceptual questions during lectures (Mazur, 1997a, 1997c).

It is important to mention that Peer Instruction was not driven by technology, but it was driven by the desire to create a student-centered learning environment in large lectures. Peer Instruction was able to utilize clickers to actively engage students in conceptual physics learning during large lectures. By doing so, Mazur began a movement of harnessing the power of technological tools in service of a clear pedagogical goal – to engage each and every student in active learning during lectures. Peer Instruction provided an opportunity for students struggling with physics concepts to explore them in small groups, working with their peers to make predictions, understand the fundamental principles, and revise their hypotheses. The focus shifted from the educator as the expert *disseminator* of information to the expert *facilitator* providing guided feedback in response to student needs and actively engaging students in their own learning. Part of the success of this pedagogical approach was students' ability to submit their responses electronically, providing them and the instructor with instant feedback about their conceptual understanding. Mazur and Crouch (2001) analyzed the data from more than a decade of Peer Instruction implementation in undergraduate physics courses. They found that clicker-enhanced pedagogy helped increase student participation, reduce student anxiety, provide continuous formative assessment, and enhance conceptual understanding.

Today, clickers are used extensively with a variety of pedagogies that stem from Peer Instruction (Kalman, Milner-Bolotin, & Antimirova, 2010; Milner-Bolotin, Fisher, & MacDonald, 2013) but not necessarily use it in the exact form suggested by Mazur. In this paper, any such pedagogy that utilizes clickers in the service of a clear pedagogical goal is referred to as clicker-enhanced pedagogy (CEP).

Using CEP in large undergraduate courses has become more popular over the past two decades, largely because of the increased accessibility to technology (Lasry, 2008; Lasry, Mazur, & Watkins, 2008; Milner-Bolotin, Antimirova, & Petrov, 2010). These days, many introductory undergraduate STEM courses in North America use some form of CEP to unpack students' conceptual understanding and promote meaningful science learning (Deslauriers, Schelew, & Wieman, 2011; Wieman, 2012).

CEP has also successfully expanded beyond large introductory courses, which often include hundreds of students, to be implemented in relatively small courses, such as upper-year undergraduate courses (Milner-Bolotin et al., 2010). In both of these situations, the purpose of CEP is to acquire information about all students' conceptual understanding. Since undergraduate courses tend to have large numbers of students (whether it is 50 or 500 students), clickers provide instant feedback that would not have been possible otherwise.

Recently, CEP has also begun entering secondary school classrooms. This is not surprising as traditional clickers today can be replaced by smart phones and other devices owned by the students, thus making the implementation of the system more feasible (i.e., Socrative system, http://www.socrative.com/). In addition, modern technology-literate students expect instant feedback on their learning. Meanwhile, secondary teachers interact with every growing numbers of students on a daily basis, making CEP an attractive pedagogy.

This places a responsibility on teacher educators to prepare teacher-candidates to use CEP in their classrooms. At the same time, teacher educators are responsible for making sure that any pedagogy they use in their classroom has a clear pedagogical goal. While the pedagogical benefits of CEP are intriguing, there is little published research on its impact in small classrooms, such as those found in teacher education programs (Milner-Bolotin et al., 2010).

Teacher education programs in Canada accept students who have already earned a Bachelor Degree in a relevant subject or who are pursuing it concurrently. Therefore, these programs are different from traditional undergraduate programs, as teacher-candidates are presumed to have mastered content area knowledge already.

One of the main goals of teacher education programs is to promote teacher-candidates' understanding of pedagogy in the context of teaching a specific subject, referred to as Pedagogical Content Knowledge (Shulman, 1986). This is especially relevant in subject-specific methods courses, such as the one described in this study. Given that the goal of methods courses is not limited to promoting content mastery, and that enrollment in methods courses is small (i.e., 10-15 students), it is necessary to reconsider the role and place of CEP in teacher education.

As such, the goals of this study are threefold:

1. To implement CEP in a small physics methods course in a teacher education program with the objective of impacting teacher-candidates' Pedagogical Content Knowledge;
2. To develop and implement a tool to assess teacher-candidates' Pedagogical Content Knowledge in the context of this physics methods course;
3. To devise the assessment tool for future use in a teacher education program.

Literature Review and Theoretical Framework

This study was guided by two theoretical perspectives: the social constructivist views of learning (Bransford, Brown, & Cocking, 2002) and the Technological Pedagogical Content Knowledge framework (Koehler & Mishra, 2009).

The constructivist views of learning and teaching emphasize understanding versus memorizing facts and procedures (Bransford et al., 2002). This is especially relevant to STEM education, where the value is placed on students' ability to apply concepts rather than recall information. According to constructivist views of learning, this can only happen if students take ownership of their learning by becoming active learners (Enghag, 2004; Laws, 1997; Milner-Bolotin, 2001). Active learning, however, does not take place in a vacuum: it happens when students interact with peers, teachers, and high/low-tech subject-specific resources (Bonwell & Sutherland, 1996; Milner-Bolotin, 2004, 2007; Milner-Bolotin, Kotlicki, & Rieger, 2007). The social aspect of learning has taken prominence in recent years in the form of social constructivist views of learning (Vygotsky, 1978) that also take into account the context in which learning occurs (Lave & Wenger, 1991).

The Pedagogical Content Knowledge (PCK) framework was proposed by Shulman (1986) and expanded by Koehler and Mishra (2009). PCK emphasizes that successful teaching requires teachers to not only be masters of content (Content Knowledge) and have deep knowledge of general pedagogical strategies, and how students learn (Pedagogical Knowledge), but also knowledge for teaching specific content, the knowledge of student potential conceptual difficulties, of relevant content-specific pedagogies, such as the ability to ask meaningful context-specific questions that promote conceptual understanding, facilitate independent thinking, and encourage student interest in science (Pedagogical Content Knowledge). This framework has since been modified to Technological Pedagogical Content Knowledge (TPCK) to include the need for teachers to be aware of modern technologies that can potentially facilitate learning (Technological Knowledge). The Technological Pedagogical Content Knowledge framework is depicted in Figure 1 (Koehler & Mishra, 2009).

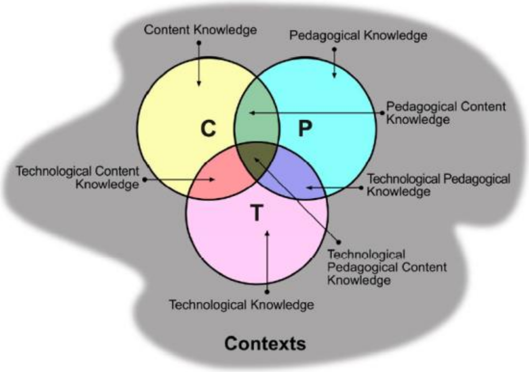


Figure 1. Technological Pedagogical Content Knowledge framework suggested by Koehler and Mishra (2009)

Figure 2 depicts a modified interpretation of these frameworks (Milner-Bolotin, Cha, Chachashvili-Bolotin, & Raisinghani, 2013). The advantage of the modified TPCK is its emphasis on the interaction between different aspects of teachers' knowledge. Thus, the biggest – initial gear is the Content Knowledge of a teacher (or a teacher-

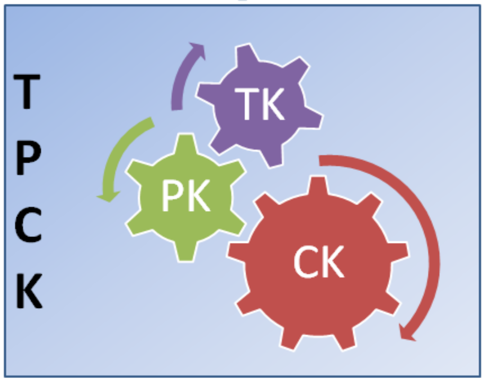


Figure 2. Modified Technological Pedagogical Content Knowledge Framework

candidate), while the Pedagogical Knowledge and the Technological Knowledge are driven by it. The modified TPCK framework also shows that taking any one of the teachers' knowledge aspects (gears) out of the framework will ruin it, as these kinds of knowledge are not interchangeable. TPCK framework is especially relevant to teacher education, as teacher-candidates have to be able to employ modern technology-enhanced pedagogies to help their students learn the subject. Thus, the Content Knowledge of a teacher (or a teacher-candidate) drives the use of relevant pedagogies and relevant educational technologies. While, CEP is at the core of this study, this research project focuses on the original PCK framework for assessment. This is reasonable, as the course discussed below focused on high- and low-tech alternatives for any tools utilized in the course and was not limited to the use of specific educational technologies.

Methods

This paper reports on the design and implementation of technology-based active engagement pedagogy in a secondary physics methods course, as well as the corresponding development of a tool to assess the Pedagogical Content Knowledge of teacher-candidates enrolled in this course.

School Context

The study was conducted at a large research university in Western Canada. This university hosts a large Teacher Education Program, which certifies high school and elementary teachers, primarily in a one-year program. The program requires all teacher-candidates in the secondary cohort to participate in a 39-hour methods course in their teachable subject(s). Methods courses are designed to provide teacher-candidates with information that will be valuable when teaching in a subject-specific environment. This includes relevant subject-specific pedagogies, technologies, activities, as well as refreshing subject-specific content included in the curriculum suggested by the Ministry of Education (BC Ministry of Education, 2012). The course described in this study is the methods course for prospective secondary physics teachers, which ran twice per week for an hour and a half, lasting thirteen weeks, during the Fall Semester 2012. The courses in the program are pass/fail, and to pass this methods course the students had to earn an 80% grade or higher.

Course Context

The course was led by one instructor and one graduate Teaching Assistant, and 13 teacher-candidates from various undergraduate backgrounds were enrolled (Table 1). Teacher-candidates earned their undergraduate degrees from a variety of institutions: either from the same institution as their Teacher Education Program, a different Canadian institution, or an international institution (denoted in Table 1 as Same, Different and International, respectively).

Table 1. Teacher-candidates' demographics

Undergraduate Program	Location of Undergraduate Degree	Teachable Subjects	Prior "clicker" experiences	Gender
Chemistry	Different	Chemistry, Physics, Junior Science	Yes	Female
Electrical Engineering	Same	Physics	Yes	Male
Engineering Physics	Same	Physics, Mathematics	Yes	Male
Physics	Different	Physics, Mathematics	Yes	Female
Physics	International	Physics	No	Female
Physics	Different	Physics, Junior Science	No	Female
Physics	Different	Physics, Mathematics	Yes	Male
Physics/Mechanical Engineering	Different	Physics, Junior Science	Yes	Male

This particular course aimed at introducing teacher-candidates to both the field of physics teaching and the field of physics education as a whole. The course objectives included teacher-candidates being able to: bring together pedagogical theory and classroom practice; become familiar with relevant educational technologies; develop skills for selecting appropriate methods, materials, and resources; and address the challenges associated with teaching physics to create pedagogically effective and supportive learning environments.

Course Assignments

The course had three major assignments. The first was designed to introduce teacher-candidates to the process of understanding how a student might think about a science topic. This involved interviewing a non-expert about a basic science topic, such as why we have seasons, and reporting on how the individual conceived of and explained the topic. Teacher-candidates were asked to probe their guest's thoughts to gain deeper understanding of where their conceptions originated. This assignment was worth 25% of their final mark. The second assignment involved a unit plan for one area of the curriculum, and four corresponding lessons. The grade for this assignment was divided into the draft (10%) and the final version (40%), allowing the instructor the opportunity to provide feedback before the teacher-candidates submitted a final version. The final assignment asked teacher-candidates to develop, critique, and adapt conceptual, multiple choice questions, or create their own. Teacher-candidates were given the option to create their own questions, or work from pre-existing questions from any available resource. One of these resources is the Mathematics and Science Teaching and Learning through Technology database of conceptual questions, designed by the research team (Milner-Bolotin, 2013). This assignment, worth 25% of the grade, was deemed of utmost importance by the research team, who place a high value on conceptual understanding, and recognize the difficulty of developing high quality conceptual questions. This final assignment is the focus of this paper, as the assessment tool was used to evaluate these question sets.

Developing an Assessment Tool

A quantitative assessment rubric was designed to evaluate teacher-candidates' Content and Pedagogical Knowledge, drawing from Shulman's (1986) model of PCK discussed above (Figure 1). We have described the design of the rubric in detail elsewhere (Milner-Bolotin, Fisher, et al., 2013). In the current paper, we will briefly outline the categories and how they were evaluated (Table 2).

Table 2. Rubric for assessing teachers' Pedagogical Content Knowledge as expressed in their conceptual questions

Content knowledge

Item	*Cognitive level (1-5)*	*Targets student difficulties (1-5)*	*Science accuracy (1-5)*	*Distractors' quality (1-5)*
1	Knowledge	Doesn't target any conceptual difficulty	Has major mistakes in the question and in solutions	All irrelevant distractors
2	Comprehension	Targets a minor concept ineffectively	Has an accurate question but an inaccurate and unclear solution	
3	Application	Targets a minor concept effectively	The question is clear and the solution is accurate but unclear	Half of the distractors are meaningful
4	Analysis	Targets a few conceptual difficulties	Both the question and the solution are clear and accurate	
5	Synthesis/evaluation	Clearly targets major conceptual difficulties	Both the question and the solution are very clear and accurate	All of the distractors are meaningful

Pedagogical knowledge

	Answer justification (1-5)	*Question clarity (1-5)*	*Multiple re-presentations (MR) (1-5)*	*Potential for inquiry (1-5)*	*Part of a sequence (1, 2)*	*Originality (1-5)*
6	No answer justification	Questions is very misleading	1 MR	Not inquiry driven	No	Exactly copied from a known source
7	Incomplete justification for correct answer (CA); no justification for incorrect answers (IA)		2 MRs		Yes	Copied with minor modifications
8	Incomplete justification for CA and IA	Question has minor problems	3 MRs	Has potential for to promote inquiry		Copied with some modifications
9	Complete and accurate justification for CA only		4 MRs			Copied with interesting modifications
10	Complete and accurate justification for CA & IA	Question is very clear as is	5 MRs			Original question

Content knowledge. Four measures were developed within this category and all were rated on a five-point Likert scale.

1) *Cognitive level:* we used Bloom's taxonomy (Bloom, 1956) to rate the cognitive level of every question. To help make consistent decision we used the verb associations described in Table 3.
2) *Target student difficulties:* The questions were evaluated based on how well they targeted specific conceptual difficulties or student misconceptions. The questions with a low rating in this category do not target any of the above and hold little value (Beatty, Gerace, Leonard, & Dufresne, 2006).
3) *Science accuracy:* We rated both the question and its justification for scientific accuracy and clarity, as these contribute largely to students' ability to answer and learn from a question.
4) *Quality of distractors:* High quality distractors add value to a question. Distractors should represent common student misconceptions and be good discriminators between the students who have high and low conceptual understanding.

Table 3. Verbs associated with categories of cognition for Bloom's Taxonomy of Educational Objectives as seen in Morrison & Walsh (2001)

Knowledge	Comprehension	Application	Analysis	Synthesis	Evaluation
Define	Describe	Apply	Analyze	Compose	Appraise
Identify	Differentiate	Calculate	Categorize	Construct	Assess
Know	Discuss	Classify	Compare	Create	Evaluate
List	Explain	Develop	Contrast	Design	Judge
Name	Rephrase	Examine	Distinguish	Formulate	
Recognize	Restate	Solve	Determine	Modify	
State	Reword	Use	Investigate	Plan	

Pedagogical Knowledge. Six measures were developed to evaluate this category. These are briefly outlined below. For a more detailed description see elsewhere (Milner-Bolotin, Fisher, et al., 2013).

1) *Justification* (5-point Likert scale): Teacher-candidates were asked to provide a justification of the answers to each question submitted. Justifications were rated for completeness and correctness, including descriptions of the correct answers as well as the distractors (incorrect answers).
2) *Clarity of question* (5-point Likert scale): Only the extremes of the Likert scale were defined (i.e. 1, 3, 5) to allow for greater flexibility in the judgement of raters.
3) *Number of representations present* (Counting): Representations include, but are not limited to, verbal, graphical, schematic, diagrammatic, and algebraic.
4) *Potential to promote inquiry* (5-point Likert scale): Rater background and expertise played a large role in this rating, therefore all cases of disagreement between raters deferred to level of experience in their respective PCK (i.e., instructor’s rating).
5) *Part of a sequence* (Binary): Concepts that are explored in sequence help foster conceptual understanding and were rated as a 2, while independent questions were rated 1.
6) *Originality* (5-point Likert scale): Relied heavily on the raters’ experience with resources to identify to what degree the materials provided in the question were original. Original materials were assigned a rating of (5), modified from an existing source (3), or directly taken from an existing source (1).

Implementing the Assessment Tool

One of the required course assignments asked teacher-candidates to design at least five conceptual secondary physics multiple-choice questions, including the explanations of the correct answer and all of the distractors (incorrect answers). Teacher-candidates' assignments were marked using the rubrics described above to evaluate their Pedagogical Content Knowledge. All questions were rated by the course instructor, the Teaching Assistant and a Research Assistant.

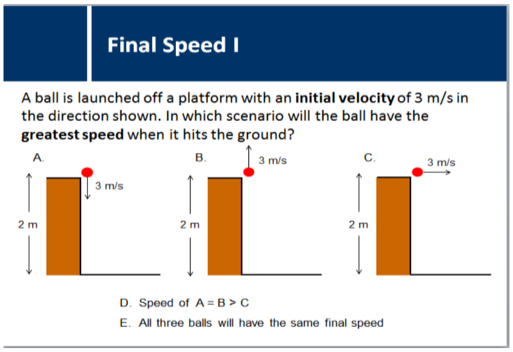
Results and Discussion

All teacher-candidates submitted at least five multiple-choice conceptual questions and corresponding answers. In total, 72 multiple-choice questions were submitted (Table 4). The three raters first independently evaluated the questions, and then compared the results to address discrepancies, which occurred in less than 10% of the ratings.

Table 4. Distribution of conceptual questions per teacher-candidate per conceptual questions assignment and in total

	Number of questions submitted per teacher-candidate and in total	Number of teacher-candidates who submitted the indicated number of questions	Percentage of teacher-candidates who submitted the questions
	5	8	62%
	6	3	23%
	7	2	15%
Total	**72**	**13**	**100%**

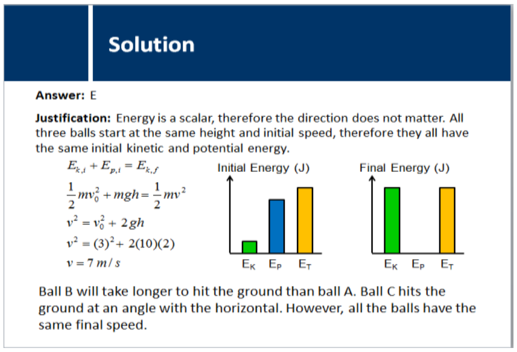
Figure 3: An example of a multiple-choice question, its solution and justification of the distractors



Final Speed I

A ball is launched off a platform with an **initial velocity** of 3 m/s in the direction shown. In which scenario will the ball have the **greatest speed** when it hits the ground?

D. Speed of A = B > C
E. All three balls will have the same final speed



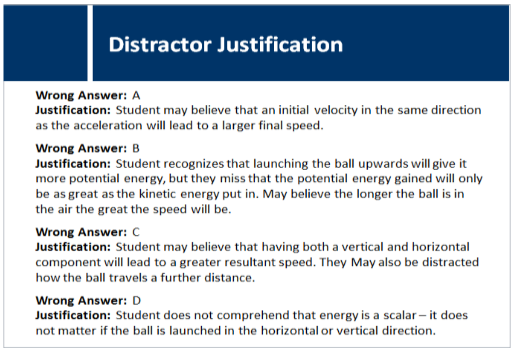
Solution

Answer: E

Justification: Energy is a scalar, therefore the direction does not matter. All three balls start at the same height and initial speed, therefore they all have the same initial kinetic and potential energy.

$$E_{k,i} + E_{p,i} = E_{k,f}$$
$$\frac{1}{2}mv_0^2 + mgh = \frac{1}{2}mv^2$$
$$v^2 = v_0^2 + 2gh$$
$$v^2 = (3)^2 + 2(10)(2)$$
$$v = 7\ m/s$$

Ball B will take longer to hit the ground than ball A. Ball C hits the ground at an angle with the horizontal. However, all the balls have the same final speed.



Distractor Justification

Wrong Answer: A
Justification: Student may believe that an initial velocity in the same direction as the acceleration will lead to a larger final speed.

Wrong Answer: B
Justification: Student recognizes that launching the ball upwards will give it more potential energy, but they miss that the potential energy gained will only be as great as the kinetic energy put in. May believe the longer the ball is in the air the great the speed will be.

Wrong Answer: C
Justification: Student may believe that having both a vertical and horizontal component will lead to a greater resultant speed. They May also be distracted how the ball travels a further distance.

Wrong Answer: D
Justification: Student does not comprehend that energy is a scalar – it does not matter if the ball is launched in the horizontal or vertical direction.

Table 5 shows the results of the analysis, including average rating value for each of the Rubric's categories and frequency of the values.

Table 5. Summary of results of the analysis of multiple-choice conceptual questions developed by teacher-candidates. The most frequent rating in each rubric category is shaded

		Content knowledge				**Pedagogical knowledge**					
		Cognitive level (Bloom) (1-5)	Targets student difficulties (1-5)	Science accuracy (1-5)	Distractors' quality (1-5)	Answer justification (1-5)	Question clarity (1-5)	Multiple representations (1-5)	Potential for inquiry (1-5)	Part of a sequence (1, 2)	Originality (1-5)
Average		3.04	4.38	4.59	4.06	4.58	4.58	2.47	3.27	1.9	1.8
Frequency of ratings	1	2	0	0	2	0	0	9	4	7	24
	2	9	2	1	1	2	3	23	7	65	39
	3	45	12	9	2	17	7	38	31		8
	4	16	15	22	14	27	7	1	25		1
	5	0	43	40	53	26	55	1	5		0
Total		72	72	72	72	72	72	72	72	72	72

Reflections on the Tool and Revisions for Future Implementation

This tool represented the research team's first effort to assess teacher-candidates' Pedagogical Content Knowledge. There were many successes and challenges during the pilot of this tool, which are reflected on here. Based on the results of the tool's first implementation, a number of modifications have been made to the tool for future use.

Firstly, not all sections of the original rubric assessed teacher-candidates' Pedagogical Knowledge or Content Knowledge directly. Part of the assignment objectives was to encourage teacher-candidates to be critical consumers of existing resources, which is why they were not required to author original questions (they were invited to do that if they wished). As such, assessing Content Knowledge cannot occur in a vacuum. Teacher-candidates must have an opportunity to articulate their reasoning for selecting this content area. In the second version and implementation of the tool, teacher-candidates will be asked to provide justification for selecting questions to provide more valuable information about their Content Knowledge. This was the largest modification to the tool as it introduced a third dimension of assessment (Table 3, Distractors' quality under Content Knowledge category), which unpacks teacher-candidates' rationale for questions, distractors, and their justifications.

Secondly, assessing Bloom's taxonomy was a great success, as it provides the teacher educator with a snapshot of the cognitive level of questioning that teacher-candidates find appropriate. This is helpful information regardless of teacher-candidates' ability to articulate their reasoning as described above. It is also important to look at teacher-candidates' Blooms taxonomy cognitive level throughout the sequence of questions submitted. For example, teacher-candidates might submit questions at the same cognitive level (Figure 4a) or they might submit questions that build from a lower level to a higher level (Figure 4b). This sends an important message about teacher-candidates' Pedagogical Content Knowledge and their ability to build meaningful question sequences.

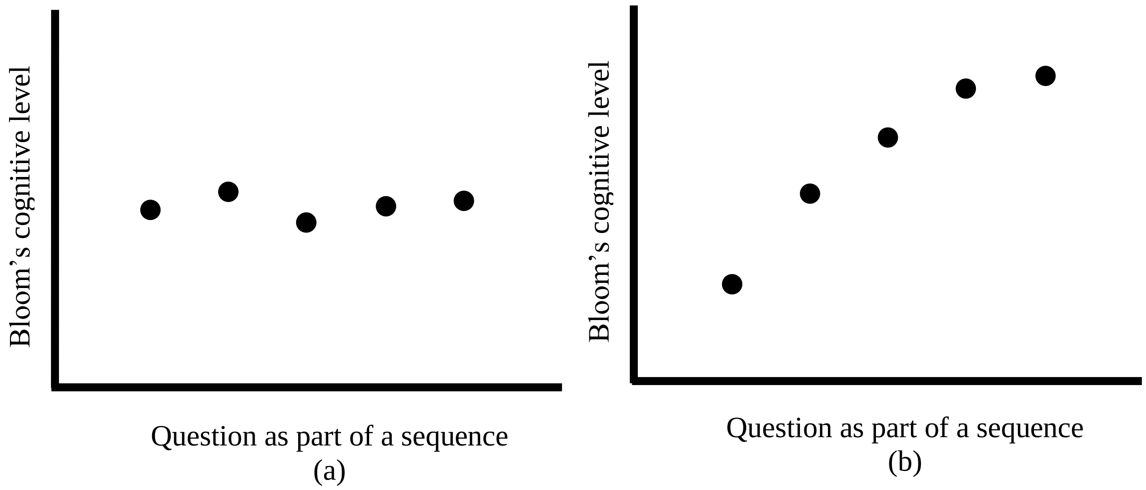


Figure 4. The rating of Bloom's cognitive level of a sequence of questions. (a) The questions maintain a steady level. (b) The cognitive level of questions is increasing.

Effective distractors are a key component of pedagogically effective multiple-choice questions. Meaningless distractors detract from the quality of a question and its ability to discern student misconceptions. There is also no ideal number of distractors to include in an effective multiple-choice question, as each distractor should address common student difficulties. Initially, the rubric was designed to identify the number of valuable distractors present in a question. However, since each question did not have the same number of distractors, this proved an inaccurate measure of the distractors' quality. By altering the scale such that only its extreme values are defined ("no useful distractors" = 1; "some useful distractors" = 3; and "all useful distractors" = 5) we were able to more clearly assess teacher candidates' ability to create valuable distractors.

In the assignment, teacher candidates were required to not only explain how the correct answer was reached, but also clarify why each of the distractors was incorrect. This was a challenging aspect to assess, as many distractors were dismissed as incomplete stages of a complete solution, and, therefore, were not explicitly mentioned. In the next iteration, teacher-candidates will be asked to identify the reasoning behind each distractor choice, including why it is incorrect and how a student might arrive at that answer. This will allow evaluators to identify whether the teacher-candidate is aware of the value each distractor will have in improving students' conceptual understanding.

Challenges arose when evaluating the clarity of a question based on the level of expertise of each rater. The instructor and Teaching Assistant both hold graduate and undergraduate degrees in physics, and the instructor has been teaching physics at a secondary and an undergraduate level for 20 years. The third researcher hails from a biology and psychology degree, and so is less familiar with the material, but holds significant expertise in human cognition. A question that was quite clear to the instructor and teaching assistant might not seem as clear to someone with less content knowledge and relevant teaching experience. In cases where the evaluators disagreed, we deferred to the expertise of the instructor and the Teaching Assistant.

Being able to incorporate multiple representations within questions and explanations is a valuable skill for a physics teacher (Milner-Bolotin & Nashon, 2012; Van Heuvelen & Zou, 2001; Zou, 2000). This ensures that different students' needs are addressed. However, when evaluating the number of representations in a question during the pilot, it was necessary to establish a standard for what should be counted as a separate entity. Text was always the first representation, and a diagram in the question or a solution each counted as one. Equations each counted as one, as did graphs. If each distractor was an equation or a diagram, the entire group was counted once. This method for counting representations proved effective, as no disagreements existed during the second implementation of the tool.

The initial tool considered a question's potential for inquiry. However, this area proved difficult to assess for two major reasons. First, it was difficult as researchers to define inquiry narrowly and clearly. Teacher-candidates also struggled to define inquiry (unpublished data) due to a diversity of perspectives. In the second implementation, the research team had discussed elements of inquiry, and how that might be presented in a multiple-choice question. However, the research team then encountered a second issue. It was unclear whether teacher-candidates saw the potential for inquiry in the same manner as the experienced instructor. It has been well document that the ability to see and seize teachable moments, such as the opportunity for inquiry depends on teachers' experience and skills (Cole & Knowles, 2000). As a result of this, the research team discussed approaching this measure from the perspective of the teacher-candidate or the prospective of the researcher. This again did not prove valuable, as it is difficult to know whether a teacher-candidate developed the questions with potential for inquiry in mind, and to what extent they see it, without an awareness of how that teacher-candidate interprets and implements inquiry in their practice. Therefore, the research team ultimately decided neither would be an accurate assessment measure. As such the next iteration of the tool will not include *potential for inquiry*.

During the course, the instructor and Teaching Assistant emphasized the importance of developing sequences of questions, building from the basics of a concept to more complex applications. This emphasis may have caused teacher-candidates to create questions that were of a lower quality, but fit within the sequence. Good questions do not need to be part of a sequence to be effective; this is a single factor contributing to the quality of a question. In the future implementation of the tool, students will not be required to create questions in sequence.

Teacher-candidates were not required to provide sources of their questions, whether they were original or adapted. The internet provides an unending source of questions and discussions, and it is nearly impossible to be aware of all resources teacher-candidates had access to during their question development. As a result, unless one of the raters had seen a question before, it was difficult to identify question’s originality. The goal of this study was to identify how well teacher-candidates were able to evaluate and adapt conceptual questions to meet their pedagogical goals. Without a baseline, this is a difficult assessment to make. In the second iteration, the originality scale will be removed. A researcher interested in using this scale as a means of identifying teacher-candidates’ ability to adapt questions might require teacher-candidates to indicate whether the question is original or adapted, and where the original question came from.

Conclusions and Future Directions

Secondary STEM teacher-candidates are faced with many challenges during their teacher education program, which are exacerbated by the assumption that they have already mastered their content area and, therefore, only need to acquire general pedagogical knowledge. However, teacher-candidates often lack content expertise in their teachable area. This discrepancy places enormous pressure on teacher-candidates and on instructors teaching discipline-specific methods courses. Consequently, teacher-candidates who are not confident in their content knowledge are likely to be unable to apply general pedagogies to the STEM context.

As a result of this study, we have developed a tool to begin assessing teacher-candidates' Pedagogical Content Knowledge during their teacher education program. In the second implementation of the tool, we will attempt to define teacher-candidates' Pedagogical Content Knowledge gains. To accomplish this, the tool will be implemented at two time points throughout the course (outset and conclusion). This will also help us establish the nature of the impact of technology-based pedagogies on the development of teacher-candidates' Pedagogical Content Knowledge.

There are many way to assess teacher-candidates' Pedagogical Content Knowledge in many different contexts. Exploration of teacher-candidates' Pedagogical Content Knowledge should not be limited to physics or technology-based pedagogies, and the current tool is adaptable to other subjects.

Limitations

Limitations in this study stem from the nature of the Teacher Education Program, and our inability to control or examine the impact of other courses on teacher-candidates' Pedagogical Content Knowledge. To fully understand the impact of a single course, it would be necessary for teacher-candidates to enroll in one course at a time. This is, of course, impractical, as the development of Pedagogical Content Knowledge does not occur in a vacuum, and pedagogies overlap across subject areas. It is also difficult to separate the impact of practicum experiences.

In addition, it is impossible to explore gains in Pedagogical Content Knowledge without assessing teacher-candidates at two time points. As discussed previously, this will be a major modification to the second iteration of the tool.

Study Significance

This study is significant for two main reasons. First, we successfully implemented an established pedagogy (clicker-enhanced pedagogy) in a novel context, a small teacher education methods course. There is a gap in the literature regarding the value of clicker-enhanced pedagogy in small courses, as they provide a very different educational experience for the students. As far as we know, the implementation of clicker-enhanced pedagogy in teacher-education STEM methods courses has not been researched. Second, we proposed a method to assess teacher-candidates’ Pedagogical Content Knowledge, which takes time to develop and is vital for their future success. The ability to assess Pedagogical Content Knowledge will allow teacher educators to get a better picture about the extent to which teacher-candidates are learning in their methods courses.

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