DEVELOPING RUBRICS FOR TPACK TASKS FOR PROSPECTIVE MATHEMATICS TEACHERS: A METHODOLOGICAL APPROACH

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This paper will focus its discussion on the tasks utilized in a study that seeks to understand the characteristics of prospective teachers' technological pedagogical content knowledge constructed in a GeoGebra-based environment. I will discuss a methodological approach that was adopted during the design of rubrics to code the data that will emerge from the study. Using Task 1 as an example to support the description, I will first deconstruct the task by providing a description that will elaborate the critical components and expectations of the task in constructing mathematics PTs' TPACK and then provide a description of the methodology. A detailed description of the design of the rubrics Task 1 will be discussed.

INTRODUCTION

Understanding teacher competence has been the focus of research for some time. The issue of teachers' knowledge of teaching for high learner achievement has contributed to the conceptualization of the term *teacher knowledge* (Beswick & Watson, 2012). Through the works of Ball, Thames and Phelps (2008), Hill, Ball and Schilling (2008) and Shulman (1986, 1987) various categories of teacher knowledge have emerged.

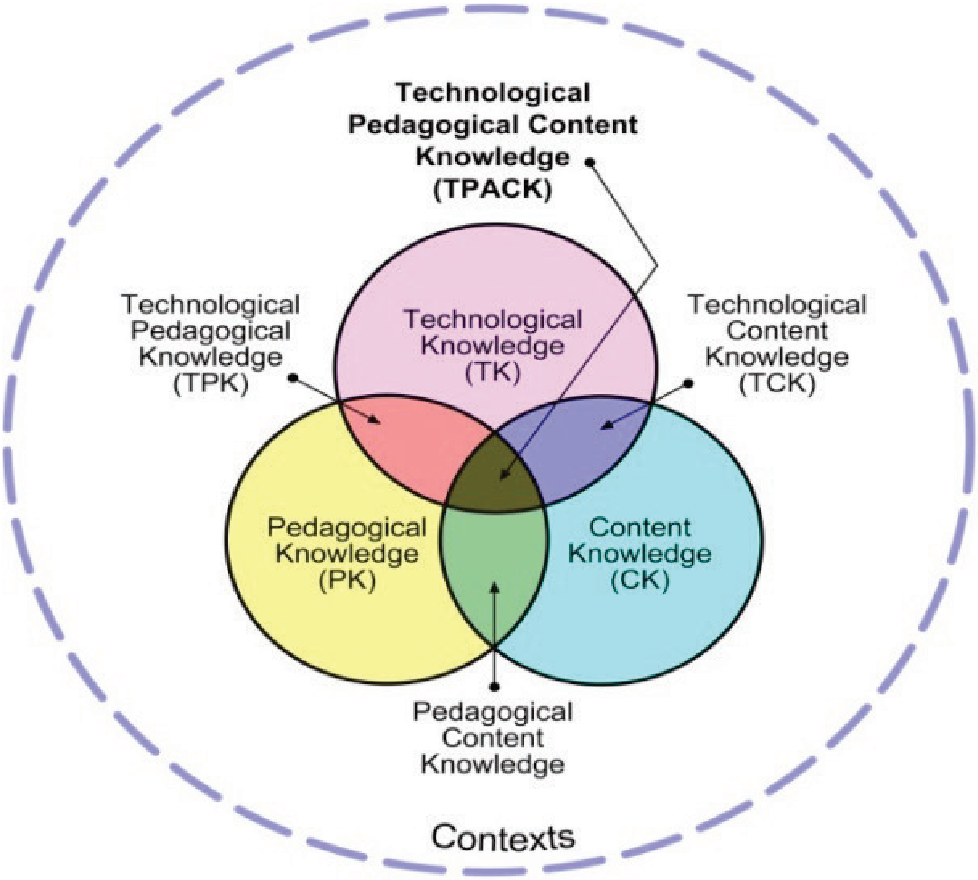
Technology in the teaching and learning of mathematics has been studied in several developmental research projects globally. Studies of computer use in school mathematics have largely examined innovations linked to developmental research projects. Many of these studies have investigated teacher participation and computer use in these developmental projects against the background of computer-based resources: for example, use of diverse interactive video materials to support a range of mathematical tasks at secondary level in England (Phillips & Pead, 1995); using GeoGebra to teach upper secondary level mathematics (Lu, 2008); the influence of dynamic geometry software on plane geometry problem-solving strategies (Aymemi, 2009). Jaworski (2010) has studied the challenges of using GeoGebra as a tool directed at generating conceptual understanding through exploration and inquiry for undergraduate mathematics students; Niess (2005) has investigated the development of prospective mathematics teachers' technological pedagogical content knowledge in a subject specific, technology integrated teacher preparation program. Collaboration and partnerships on projects and studies on technology in mathematics in higher education have recently been on the rise, with developing the use of technology to support teaching and learning being identified as a priority in most of these projects.

Although the technology community has advanced the benefits of integrating technology in education, there are discerning voices that have cautioned on learning in technology-based environments. For example, research has shown that technology tools can engage students in authentic learning opportunities that enhance the development of basic and higher-order skills but United Nations Educational, Scientific, and Cultural Organization (UNESCO, 2008) warns that the success to integrate lies in the ability of the teacher to effectively integrate technology into classroom lessons. Drijvers and Trouchè (2008) have acknowledged the double jeopardy of teaching and learning mathematics in a technology-based environment, given the complexities of teaching and learning and the complexities of use of the technology tool. Mathematics teachers should be knowledgeable about mathematics content, pedagogy, learners in relation to technology integration in learning. Drijvers and Trouchè (2008, p. 364) elucidate on the *double reference* phenomenon which is the double interpretation of tasks by teachers and learners giving an example where "tasks that address mathematical concepts may be perceived to address how the computer environment would deal with such a task."

Teacher education programs are proposing that undergraduate courses in mathematics integrate technology into teaching with activities that promote mathematical thinking. In pursuit my interest in technology integration in mathematics learning I want to examine prospective teachers (*hereafter referred to as PT*) re-learning mathematics and learning to teach mathematics with technology, specifically the GeoGebra software. As mediators of mathematics learning PTs should experience technology first if they are to incorporate it into classroom mathematics learning. It is worth noting that teacher beliefs on mathematics influence their decisions on pedagogical practices. It is essential to understand the beliefs that influence teachers' decision to use technology as these may be barriers to using technology for instruction (Hew & Brush, 2007). In the same light, intensified research is needed to improve and understand mathematics learning in technological environments; particularly, what processes and actions should be illuminated and addressed when dealing with technological artefacts in mathematics instruction. In their study on South African teachers' use of dynamic geometry software in high school classrooms, Stols and Kriek (2011) found that teachers' behaviour towards dynamic geometry is influenced by the perceived usefulness of technology in the classroom. Teachers' perspectives on teaching and learning mathematics in technology-rich environments should be illuminated and explored at teacher preparation level. Niess (2005) reiterates that teacher' decisions to implement technology into their teaching practice rests on their knowledge of technology, knowledge of mathematics, and knowledge of teaching.

THEORETICAL FRAMEWORK

Mathematics teacher education programs need to prepare PTs so that they are able to consider the mathematics content, the technology in use and the pedagogical methods employed in teaching the content. In such programs, knowledge of technology should integrate both mathematical knowledge and knowledge about the technology tools. I contend that knowledge is derived from experience for which I conjecture that teacher knowledge is influenced and framed by teacher practical experiences with tools. Researchers in the field of technology integration employ the technological pedagogical content knowledge (*herein referred to as* TPACK) framework to study the development of teacher knowledge about technology integration (Lee & Hollebrands, 2008; Mishra & Koehler, 2006; Niess, 2005). Premised on the Lee Shulman's framework of pedagogical content knowledge (PCK), teacher knowledge for technology integration is built on the interaction among three bodies of knowledge: domain-specific content knowledge, pedagogical knowledge, and technology knowledge. I employed the technological pedagogical content knowledge (TPACK) framework as a lens to study prospective secondary mathematics teachers' knowledge development as they work on a set of geometry tasks where such tasks are designed to advance both mathematics knowledge and technology knowledge (see diagram below).



TPACK framework and its knowledge components (http://tpack.org)

Mishra and Koehler (2006) explicate that TPACK is the interaction of these bodies of knowledge, both theoretically and in practice, to produce the types of flexible knowledge needed to successfully integrate technology use into teaching. Mishra and Koehler (2006) explicate that TPACK is the interaction of these bodies of knowledge, both theoretically and in practice, to produce the types of flexible knowledge needed to successfully integrate technology use into teaching. The TPACK constructs as described by Mishra and Koehler (2006, p. 63) are conceptualized in the study as follows: *Content Knowledge* is knowledge of geometry concepts, theories, ideas, established practices and approaches toward developing such knowledge. *Pedagogical Knowledge* is knowledge of teaching and learning circle geometry. *Technology knowledge* is knowledge about GeoGebra and working with GeoGebra. *Pedagogical content Knowledge* is knowledge of pedagogy for teaching of circle geometry; *Technological Content Knowledge is the* understanding of how GeoGebra is best suited for addressing learning circle geometry. *Technological Pedagogical Knowledge* is the knowledge required for understanding the constraints and affordances of GeoGebra. *Technological Pedagogical Content Knowledge* is knowledge about teaching circle geometry with GeoGebra effectively.

This discussion is part of an ongoing study that intends to examine knowledge development of PTs enrolled in a secondary mathematics method course. The study focuses on mathematical thinking processes of the prospective teachers as they learn or re-learn school geometry in the GeoGebra based environment (content knowledge) and by examining what characterizes the prospective teachers' pedagogical content knowledge for teaching geometry with technology (technological pedagogical content knowledge).The knowledge development is studied in the context of investigating PTs' actions as they work on the geometry content and pedagogical tasks developed in a GeoGebra-based environment.

Often TPACK knowledge development has been studied through the use of Likert-type scales, appropriating the use of pre- and post testing to measure the development. Acknowledging the weaknesses of the Likert instrument and taking into consideration the design of the study, I decided to employ the use of rubrics. Clement, Chauvot, Philipp, & Ambrose, 2003) contend that rubrics serve a dual purpose (i) providing insights into written responses and (ii) use of numerical scores to statistically analyze responses. A rubric is a guideline that describes the characteristics of the different levels of performance used in scoring or judging a performance. An analytic rubric was preferred because it allowed for different levels of achievement of performance criteria to be determined. The PTs responses were scored according to the analytic rubric that I designed to capture TPACK-related evidence basing on the work of Miheso-O'Connor (2011) who employed the use of rubrics to measure pedagogical content knowledge proficiency in teaching mathematics. As such, the design of the rubric was guided by the question "What would the participant need to know or be able to do to successfully respond to this task?"

The rubric used specific scores based on a five-point qualitative scale (ranging from 0 to 4) to capture the PTs' proficiency in the three main knowledge domains of content, pedagogy and technology. To generate the descriptions, I conducted an item analysis of each task of the piloted tasks according to the descriptors that I developed from the three sources of evidence: TPACK constructs as conceptualized in the study, the Duval (1995) model of *perceptual* and *cognitive* perspectives on geometry reasoning and the processes of instrumental genesis in the GeoGebra construction tasks. Each task was first categorized according to the Duval's geometry apprehension and the TPACK construct that it is testing. A rubric was developed for each of the sub-task resulting with a total of 14 rubrics. An analysis of the tasks was essential in determining the reliability and validity of the items that will provide a robust evaluation of the quality of items in determining what characterizes PTs' TPACK for learning teaching geometry in technology-based environment.

MEETING THE TASKS

The tasks selected for this study have elements of the three bodies of knowledge: content knowledge, pedagogical knowledge, and technology knowledge. Although the main emphasis of the tasks is to intertwine content, pedagogy and technology, I have decomposed the tasks based on the Stylianides & Stylianides (2010) and Biza, Nardi, &Zachariades (2007) recommended features of mathematics pedagogy and content tasks for PTs. The technology tasks are drawn from Laborde (2001) recommended features.

Stylianides & Stylianides (2010) propose that the nature of mathematics tasks for preparing teachers should engage participants in mathematics content; link mathematical ideas suggested by theory or research; and engage participants in mathematical activity from the perspective of a teacher of mathematics. Similarly, Biza, Nardi, & Zachariades (2007) suggest that the structure of tasks should explore (i) subject-matter knowledge, (ii) types of pedagogy and, (iii) types of didactical practice that describe feedback to learner's response.

The technological feature of the tasks were structured as suggested by Laborde (2001, p. 293) who categorizes *dynamic geometry environment as:*

> (1) tasks for which the technology facilitates but does not change the task (e.g., measuring and producing figures); (2) tasks for which the technology facilitates exploration and analysis (e.g., identifying relationships through dragging); (3) tasks that can be done with paper-and-pencil, but in which new approaches can be taken using technology (e.g., a vector or transformational approach); and (4) tasks that cannot be posed without technology (e.g., reconstruct a given dynamic diagram by experimenting with it to identify its properties – the meaning of the task comes through dragging). For the first two types, the task is facilitated by the technology; for the second two, the task is changed by technology.

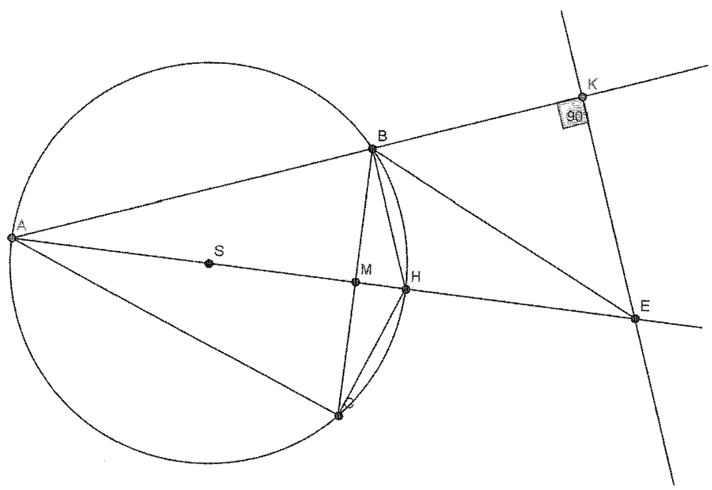
The tasks comprise of a series of content-based and pedagogical-based questions involving typical problems based on a Grade 11 geometry level, requiring the participants to construct geometrical objects with the intent to infer properties, generalities, or theorems through the different dragging modalities of GeoGebra[4]. In deconstructing the tasks, I have addressed three components of: (a) the critical components of the task, (b) the actions required to complete the task, and (c) the TPACK construct(s) addressed by the task or the sub-tasks.

DECONSTRUCTING TASK 1

Task 1 comprises of content-based and technology-based questions involving typical problems based on Grade 11 geometry, requiring the PTs to interpret and construct geometrical objects with the intent to infer properties, generalities, or theorems through the different dragging modalities of GeoGebra[4.2] (see below). The major purpose of the task is to use multiple representations to represent and explain the task in different situations that provide opportunities for application of the cognitive apprehensions and cognitive processes for geometric reasoning.

TASK 1

The diagram below shows a circumscribed circle with centre S. Triangle ABC has AB = AC. Angle A is acute and AB is extended to K. AS extended cuts BC at M and the circle at H. BE bisects $C\hat{B}K$. BE meets AS produced at E. AB when produced, is perpendicular to EK.



(a) Write down and label all the geometric shapes/figures that you see in the above diagram. E.g. ΔABC

(b) Which triangles in the diagram are congruent? Justify.

(c) Use GeoGebra to construct the diagram.

The critical components of the task

The mathematical objective of the task is to compose and decompose a shape within a given diagram by reflecting an understanding of geometrical concepts and spatial representations derived from the figure. Task 1 is based on the argument by Gagatsis, Deliyianni, Elia, Monoyiou, & Michael (2009: 37) that "geometrical figures are simultaneously concepts and spatial representations". This argument suggests that "diagrams in two-dimensional geometry play an ambiguous role: on the one hand, they refer to theoretical geometrical properties, while on the other, they offer spatio-graphical properties that can give rise to a student's perceptual activity" (Larborde, 2004:1). The major purpose of this task is to make a mathematical argument on generalizations and conjectures when interacting with the diagram, which Herbst (2004) purports that it provides an opportunity to make reasoned conjectures.

What action is required to complete the task?

The task requires the PTs to make interpretations and constructions. The task provides an opportunity to explore the PTs' prior knowledge regarding definitions, properties, theorems and constructions of geometric figures, deductions that can be made about these figures and the ability to transform a static drawing to a dynamic construct. Tasks 1(a) and (b) examines the ability to discriminate and recognize in the perceived figures and several subfigures and as such this task is concerned with examining the PTs' visual spatial ability: the mental ability to manipulate objects and their parts in a two dimensional space. Task 1(b) solidifies the deductions made in (a). Task 1 (c) provides the PTs with opportunites to explore construction strategies and to solidify the idea that these constructions are based on geometric properties identified in (a) and (b). In this task PTs invent strategies for constructing a perpendicular bisector, a cyclic quadrilateral, isosceles triangle, etc, by building more sophisticated constructions, such as inscribing an isosceles triangle in a circle.

The TPACK construct(s) addressed by the task

The task comprises of content-based and technology-based questions. The task is testing three TPACK constructs of CK and TCK. Tasks 1 (a) and (b) test the CK that require geometry competence. A conceptual understanding of aspects of circle geometry should be identified by making connections between concepts. Task (c) tests the TCK that requires competence to use GeoGebra to mediate geometry proficiency. The PT is required to identify the geometrical relationships between the objects created on the computer and original constructions. To successfully do the identification, PTs need to visualize the different configurations of the figures and use GeoGebra construction tools such as the 'drag mode' tool to explore of conjectures.

A model solution of Task 1

Task 1(a) requires perceptual apprehension of the figure. There are at least 17 figures that can be identified comprising a circle and composite circle, triangles and quadrilaterals, suggesting that one should be able to identify at least three types of figures:

1. Circle S, 2 semi-circles, 4 segments
2. Triangles: ΔABM, ΔACM, ΔBMH, ΔMHC, ΔBHE, ΔBKE (all single triangles);
   ΔABC, ΔABH, ΔAHC, ΔBHC, ΔBME, ΔABE, ΔAKE (all composite triangles)
3. Quadrilaterals: ABHC, BKEH, BKEM (accepts kite ABHC, cyclic quad ABHC)

Task 1(b) tests knowledge of congruency.

Required to show that:

(i) ΔABH ≡ ΔACH or equivalent

Proof: AB = AC given
Ĉ = 90° (< in semi-circle)
B □=90°(< in semi-circle)
$AH\ common$

$\therefore \Delta ABH \equiv \Delta ACH\ \ (SAA)$

$(ii)\ \Delta ABM\ \equiv\ \Delta ACM$

$Proof: AB\ =\ AC\ given$

$CM\ =\ BM\ (\Delta ABH\ \equiv\ \Delta ACH)$

$C\hat{A}M =\ CBM\ (\Delta MHB\ \equiv\ \Delta MHC)$

$AM\ common$

$\therefore \Delta ABM\ \equiv\ \Delta ACM$

$(iii)\ \Delta BMH\ \equiv\ \Delta MHC$

$Proof: HB\ =\ HC\ (\Delta ABH\ \equiv\ \Delta ACH)$

$CM\ =\ BM\ (\Delta ABH\ \equiv\ \Delta ACH)$

$C\hat{H}M =\ B\hat{H}M\ (\Delta ABH\ \equiv\ \Delta ACH)$

$AM\ common$

$\therefore \Delta MBH\ \equiv\ \Delta MHC$

Task 1(c) requires a construction of the diagram with GeoGebra. A model solution must reflect an ability to transform the following statements from static to dynamic construction on GeoGebra:

Construction of

Triangle ABC
AS extended cuts BC at M and the circle at H.
BE bisects $C\hat{B}K$.
BE meets AS produced at E.
AB when produced, is perpendicular to EK

THE RUBRICS

Following is a discussion of the intensity of the methodological process employed to develop the rubrics. The rubrics had to be specific and explicitly address the expectations of the tasks. However, I acknowledged that the rubrics at this stage should be flexible considering that I was developing description of anticipated typical responses that might be availed. As such, the constructed rubrics are to be a guideline to analyzing the PTs responses. The descriptions developed were built from the expected ideal solutions devised in the memo. I utilized a five-point qualitative scale ranging from a score of 0 for non response and/or incorrect response to a score of 4 for a correct response. I used a reverse method in determining the description starting with level 4 building down to level 0. The description for level 4 was based on the ideal correct solution, where all traits in the description are realized. In some instances, examples had to be given as a guide for some descriptions to make clear where certain responses will fit.

Task 1(a)

This task tested PTs' geometry content knowledge. The PTs were required to "Write down and label all the geometric shapes/figures that you see in the above diagram". To avoid misunderstandings an example was indicated to lead the respondent on the expected answer. In levels 4 – 1, the descriptions reflect that respondent will correctly identify and label the figures with at least mentioning the three figures (see rubric 1(a)). I expect the PTs' to know basic figures i.e. circle, triangle, quadrilaterals. Despite this, Level 1 caters for responses that I anticipate mention 2 figures correctly regardless of the type of figure. I considered that labeling could be a constraint to some respondents. There are at least 17 figures that one can recognize in the perceived figures and several subfigures, an interval of number of figures had to be determined for the 4 levels. As mentioned it was justified that the lowest number of figures should be 3 and the maximum for a response that considered the figures built from the three basic figures is 17. However, an exceptional case would be an inclusion of semi-circles and circle segments. This statement qualifies the *at least 17* figures identified.

level	description
0	No shape/figure identified
1	Correct identification and labeling of at least 2 figures even if similar e.g. all triangles
2	Correct identification and labeling of 3 - 9 figures including three major shapes: circle, triangle, quadrilaterals
3	Correct identification and labeling of 10 - 16 figures including three major shapes: circle, triangle, quadrilaterals
4	Correct identification and labeling of at least 17 figures including three major shapes: circle, triangle, quadrilaterals

Table 1: Rubric 1(a)

Task 1(b)

This task tested PTs' geometry content knowledge. The PTs were required to show and justify "which triangles are congruent". In levels 4 – 1, the descriptions reflect that the respondent will correctly identify the congruent triangles basing on the recognition that AH is the diameter of the circle (see rubric 1(b)). The mathematical statement given in the responses for these levels should reflect both the visualization and reasoning process enacted. However, we noted that a correct identification or configuration of the diagram to show congruency may not necessarily be aligned with the correct reasoning or justification. As such, the explanations were coded with respect to the levels as correct, incomplete correct, faulty, and no explanations. For instance, Level 3 differs with level 4 in that the level 3 response provides a correct response with incomplete explanations.

level	Description
0	incorrect identification of congruent Δs or no response
1	Correct identification of at most 3 congruent triangles; no explanations
2	Correct identification of at most 3 congruent triangles ; Faulty explanations
3	Correct identification of at most 3 congruent triangles ; incomplete correct explanations
4	Correct identification of at most 3 congruent triangles. Correct explanations using geometric reasoning, recognizing in reasoning that AH is diameter.

Table 2: Rubric 1(b)

Task 1(c)

This task tested PTs' geometry technological content knowledge. The PTs were required to "Use GeoGebra to construct the diagram". In this task there is interplay between GeoGebra and geometry knowledge. The intention is for the descriptions to capture both knowledge of GeoGebra and geometry knowledge. The response for the task requires a proper use of GeoGebra, suggesting that in constructing the diagram with GeoGebra, there are three possibilities; a correct construction, an incorrect construction or no construction noting the level of geometry knowledge (see rubric 1(c)). A level 4 description indicates a response that shows a correct construction at a glance, suggesting that during the construction process, a complete exploitation of the affordances of GeoGebra was realized, resulting with short concise sequence of construction. A Level 3 description shows a response that correctly constructs the diagram but uses a long concise sequence of construction. A level 2 description is for an incorrect disjointed construction that indicates less exploitation of affordances of GeoGebra. At this level there is no systematic approach to the construction with a possibility of disorientation when a point is dragged. A systematic approach would optimally use GeoGebra as a dynamic geometric tool. At level 1 the response indicates an attempt to construct but not necessarily the required diagram, reflecting some technical knowledge but lack of geometry knowledge.

level	description
0	In ability to use GeoGebra
1	Some figure drawn, missing other details e.g. ΔABC not isosceles
2	incorrect disjointed construction, less exploitation of affordances of GeoGebra, no systematic approach to construction, possibility of disorientation when point is dragged
3	Correct construction at a glance, complete exploitation of affordances of GeoGebra, long sequence of construction
4	Correct construction at a glance, complete exploitation of affordances of GeoGebra, short concise sequence of construction

Table 3: Rubric 1(c)

CONCLUSION

This paper provided a methodology for developing rubric to analyze PTs' TPACK. The development of rubric is a lengthy process that requires a negotiation that would cater for all possible strategies for the solutions. Distinguishing between cases required a negotiation between the theoretical to the practical. This process necessitated mediation between item analysis of the tasks and descriptions of the rubrics that focus on the TPACK constructs. The tasks and the rubrics were rigorously tested for coherence, reliability, and validity during this process. To test for validity and reliability I ensured that the description were explicit and appropriate for each level. There was also a need for coherence between the expectation of the task and the rubric descriptions. I acknowledge that at this level of constructing descriptions without the data at hand, rubrics constructed should be flexible to accommodate all possible responses.

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