Survey design considerations for capturing teachers' mathematical digital competency: a vignette approach

Eirini Geraniou[1] and Nicola Bretscher[2]

[1]IOE, UCL's Faculty of Education and Society, UK; e.geraniou@ucl.ac.uk

[2]IOE, UCL's Faculty of Education and Society, UK; n.bretscher@ucl.ac.uk

There is a substantial research base demonstrating the benefits and need for employing technology in mathematics education. However, teachers' competencies in using digital technology in their teaching have not been widely investigated. We therefore carried out a small-scale research study to investigate how to develop and assess mathematics teachers' competencies in teaching with technology, specifically their Mathematical Digital Competency (MDC). We designed a prototype survey for assessing teachers' MDC using a vignette approach. In this paper, we discuss our vignette design considerations for the survey items in our efforts to capture mathematics teachers' MDC and present some of our initial findings from trialling it with 114 pre-service teachers.

Keywords: Teacher survey design, mathematical digital competency, mathematics teachers, digital technology, vignette method.

Introduction

Previous research has detailed the benefits and challenges of integrating Digital Technologies (DT) into mathematics teaching (e.g., Clark-Wilson & Hoyles, 2017). The benefits of technology-enhanced mathematics instruction are that it can contribute significantly to pupils' achievements (Young, 2017) and better prepare them with the mathematical knowledge and skills needed in their future careers (Hoyles et al., 2010). However, a key challenge is that relatively little is known about the competencies that mathematics teachers need to develop to integrate DT into their teaching. Over the recent years, the training and support offered to teachers has been at a generic level, e.g., European Commission's Digital Education Action Plan 2021-2027, the European Framework for the Digital Competence of Educators, the Welsh Digital Competence Framework in Education and the free self-reflection tool, SELFIE. Subject-specialists are therefore burdened with the task to self-identify the skills and pedagogic strategies for embedding technology into their practice. Mathematics teachers' subject-specific competencies have been found to be positively correlated to teaching quality, which in turn affects pupil outcomes (Kunter et al., 2013). We have thus been interested in investigating how to conceptualise, assess and support mathematics teachers' Mathematical Digital Competency (MDC; Geraniou & Jankvist, 2019) for teaching with the use of DT. Tabach (2021) discussed the readiness (or not) towards characterising competencies for teaching mathematics in the digital era, which if nothing else supports the need and value of our work. In a first step towards achieving our goal, we carried out a small research study with 114 pre-service mathematics teachers studying at a University in England, UK, in the academic year 2021-2022. Vignettes (Skilling & Stylianides, 2020) have been shown to be an effective method for capturing teacher competencies, however, to our knowledge, they have not been used to capture teachers' mathematical digital competency. Hence, our research question is: *How does a vignette-approach in a self-assessment survey capture teachers' MDC and support reflection on the use of DT in teaching mathematics?*

In this paper, we start off by presenting our current conceptualisation of teachers' MDC in light of relevant literature, which formed the basis for designing a survey using a vignette design approach, that stimulated teachers' reflection on technology-enhanced pedagogical practice. To exemplify our design considerations for our survey, we present a survey item in detail arguing about our rationale and design decisions. We present some of our initial findings from piloting this survey with pre-service teachers in England and conclude with some reflections on the design challenges we were faced with and suggestions for designing survey items that capture teachers' MDC.

Conceptualising teachers' MDC

In conceptualising teacher competency or in other words the set of skills they employ to teach, we built on our own past research. Geraniou and Jankvist (2019) conceptualised the interplay between mathematical competencies and digital competencies and introduced Mathematical Digital Competency (MDC) in recognition of the need for *learners* to develop competency in using technology to solve mathematical problems. Inspired by and combining elements from three different theories, the Danish mathematics competencies framework, KOM (Niss & Højgaard, 2019), the Theory of Instrumental Genesis (Trouche, 2005) and Vergnaud's (2009) Theory of Conceptual Fields, they derived three characteristics that showcase learners' posession of MDC. These are:

> "[MDC1]: *Being able to engage in a techno-mathematical discourse*. In particular, this involves aspects of the artefact-instrument duality in the sense that instrumentation has taken place and thereby initiated the process of becoming techno-mathematically fluent.
>
> [MDC2]: *Being aware of which digital tools to apply within different mathematical situations and context, and being aware of the different tools' capabilities and limitations*. In particular, this involves aspects of the instrumentation–instrumentalisation duality.
>
> [MDC3]: *Being able to use digital technology reflectively in problem solving and when learning mathematics*. This involves being aware and taking advantage of digital tools serving both pragmatic and epistemic purposes, and in particular, aspects of the scheme-technique duality, both in relation to one's predicative and operative form of knowledge" (Geraniou & Jankvist, 2019, p.43).

Our intention was to adapt this conceptualisation for *teachers*. As a first step, we relied on Geraniou et al.'s (2022)[1] initial conseptualisation of MDC for teaching or MDCT, which includes pedagogic elements in the above framework for learners' MDC to better match teachers' MDCT:

> [MDCT1]: Being able to engage in a techno-mathematical discourse **at a meta-pedagogic level**.
> [MDCT2]: Being aware of which digital tools to apply within different mathematical situations and context, and being aware of the different tools' capabilities and limitations, **so as to think, and act, pedagogically with these tools,** while considering the benefits and limitations of these.
> [MDCT3]: Being able to use digital technology reflectively in problem solving and when doing (learning **or teaching**) mathematics (Geraniou et al., 2022, p.7).

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[1] For more information on the networking of the KOM framework, the theory of instrumental genesis and conceptual fields, the reader is encouraged to have a look at our past papers Geraniou & Jankvist (2019) and Geraniou et al. (2022).

We reviewed numerous authors' work regarding teachers' practice, skills, beliefs in general, but also in terms of DT, in order to find an acceptable definition for MDCT. For example, Fauth et al.'s (2020) work on teachers' beliefs and specifically their orientation towards ICT since this is an important factor in teachers' use of technology (Drijvers et al., 2021) and Thurm and Barzel's (2022) work on a multidimensional analysis of teachers' beliefs about teaching with technology. We felt though that Niss and Højgaard's (2019) definition of mathematical competence: "someone's insightful readiness to act appropriately in response to all kinds of mathematical challenges pertaining to given situations" (p. 12), was key in helping us decide that we should understand MDCT as the set of skills teachers need (or have) to select and implement DT in productive ways, as claimed by Geraniou et al. (2022).

Methods

The MDCT self-assessment survey tool consisted of two parts. The first part was borrowed from an existing survey by Thurm and Barzel (2022) and was used in an effort to survey teachers' beliefs about the use of technology in mathematics teaching and learning (as inspired by the work of Fauth et al., 2020, who stated the importance of teacher's beliefs) and which will not be discussed in this paper. The second part focused on 'assessing' teachers' MDCT via 3 survey items, designed using a vignette approach (Skilling & Stylianides, 2020), as it will be described in detail later. These items involved classroom scenarios (or *vignettes*) and multiple-choice options for teachers to select their preferred teaching approach in response to the presented scenario.

The MDCT survey was piloted initially with 11 mathematics educators at the UCL weekly Mathematics Education Special Interest Group (SIG) seminars. Based on the feedback we received from mathematics educator colleagues, we refined the MDCT survey items and trialled them with 114 pre-service teachers, studying on 3 different Initial Teacher Education (ITE) programmes at a University in England, UK. We made the decision to pilot it with pre-service teachers, before refining it further and trialling it with in-service teachers. The 3 survey items focused on 3 different mathematical topics and involved 3 different DTs, while being mapped to at least 1 element of MDCT. The first one was on Circle Theorems and involved the use of the GeoGebra dynamic geometry system and was mapped to MDCT2. The second one was on Properties of Regular Polygons and involved the use of a programming language, Scratch, and was mapped to MDCT1. The third one was on Order of Operations and involved the use of a Calculator, and was mapped to MDCT3. We invited pre-service teachers for a 30-minute interview to further discuss their responses on the 3 vignette-style survey items and 6 volunteered. These 6 interviews helped us gain insight into their survey responses, how the survey items supported their reflection on practice and critical research engagement, but also allowed us to reflect on the vignette-approach for the design of the survey items.

A vignette framework for educational research

Vignettes, or 'stories' as they are sometimes described as, have been used as tools for "modelling, teaching, discussing, researching behavior and understanding in general education, legal education, health science, social sciences and behavioral sciences" (Jeffries & Maeder, 2006, p.1). There have been numerous definitions of vignettes in relevant literature, but for our work, we consider vignettes as "written, visual, or oral stimuli, aligned with relevant research paradigms and methodologies, reflecting realistic and identifiable settings that resonate with participants for the purpose of provoking responses, including but not limited to beliefs, perceptions, emotions, effective responses, reflections, and decision making" (Skilling and Stylianides, 2020, pp.542-543).

Skilling and Stylianides (2020) argued for the effectiveness of vignettes in educational research, as they enable researchers to gain insights into teachers' perspectives about certain phenomena. Phenomena may include for example student engagement in mathematics or student understanding in mathematics or even teachers' mathematical digital competency, as we argue in this paper. Nind and Pepin (2009) showcased that following a vignette methodology allows us to connect research with practice that may lead to a change of practice by practitioner-researchers. One of our aims for using a vignette-design approach in the MDCT survey was to prompt pre-service teachers to self-assess, reflect on, take first steps to develop MDCT or further consolidate their existing MDCT.

To design the 3 vignette-style items in the MDCT survey, we followed Skilling and Stylianides's (2020) vignette framework, which consists of three key elements, Conception, Design and Administration. Conception "includes characteristics that are central to the research phenomena and the aims of the research, including: capturing content, realistic and hypothetical portrayals, and purpose/function" (p.544). Design includes charactersistics, such as "presentation, length, settings and terminology, open or closed questioning, participant perspectives, and piloting" (p.546). Administration concerns how the vignettes are administered and "the opportunities for participants to respond […]: instructions, timing and responses, and delivery mode and frequency" (p.548).

The Scratch MDCT survey item as an exemplar of a vignette-design approach

All our 3 MDCT survey items were designed following the vignette framework by Skilling and Stylianides (2020). In this paper, we decided to use the Scratch MDCT survey item as an example for sharing our vignette design considerations for the MDCT survey. We developed the Scratch item using a vignette narrative describing a construction activity given to a fictitious Year 7 mixed-attainment mathematics class of students by the class teacher. This item is presented in Figure 1. Below we analyse how we applied the vignette framework by focusing on its three key elements, while using italics to demonstrate our approach in terms of the framework's characteristics.

Conception: We captured the *content* by presenting the information about the *setting* in the fictitious classroom scenario in a structured manner, as shown in Figure 1. The narrative was written in such a way so as to portray a *hypothetical*, yet *realistic* situation and therefore resonate with a construction activity the teacher would be familiar with. We need to emphasise, though, that all pre-service teachers would be familiar with constructing an equilateral triangle, but they may not necessarily be familiar with how to construct one using the Scratch programming tool. This was one of our rationales for including images of the Scratch codes of two fictitious students, Nick and Lenny, and the desired output of a correctly constructed equilateral triangle. We also wanted to create two contrasting situations. One of the students, Nick, used a 'loop command' for his code, but accidentally used the wrong size for the sprite's 'turn'. The other student, Lenny, did not use the powerful idea of the 'loop command', but instead repeated the same two steps three times, to construct the three sides of the equilateral triangle, using the correct size for the sprite's 'turn'. Our *purpose*, therefore, was to create a concrete situation for pre-service teachers to identify their practices if they were in such a situation.

Design: The vignette item was presented in written format and included images from code created in

Q2. Scratch

Year: 7

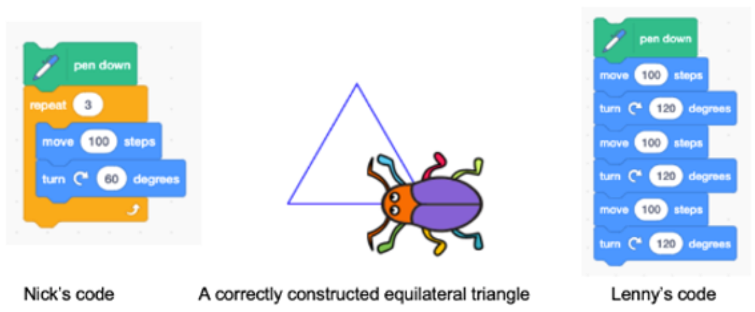
Attainment: Any

Mathematical Topic: Properties of regular polygons, e.g. angles

Learning Goal: To understand interior and exterior angles in an equilateral triangle

Tool/Software: Scratch programming software

Scenario: You have set students the task of constructing an equilateral triangle on Scratch. As you walk around the room, you notice that two students, Nick and Lenny, produced different codes



How likely are you to respond in any of the following ways?

(a) Praise Nick for using a loop command correctly and point out to Lenny that he's made a mistake with the angles.

Very unlikely	Unlikely	Neither	Likely	Very likely

(b) Praise Lenny for producing correct code and point out to Nick he's made a mistake with the angles.

Very unlikely	Unlikely	Neither	Likely	Very likely

(c) Show both methods to the whole class and run a discussion comparing the pros and cons of each.

Very unlikely	Unlikely	Neither	Likely	Very likely

Figure 1: The Scratch MDCT survey item

the Scratch programme and the desired outcome of a correctly constructed equilateral triangle. The *setting* was described in simple language, avoiding the use of any *technical terms* relevant to the Scratch environment (e.g., 'sprite'). We introduced the term 'loop command' to enable, even those that may not be familiar with Scratch, to understand what the "repeat (3)" in Nick's code means. The pre-service teachers were asked in a *closed-questioning style*, to rate how likely (or not), from their own *perspective*, they were to follow any of the three given aproaches if they were in the fictitious situation presented in this vignette. Drawing on our experiences as teacher educators and researchers, we designed the 3 presented approaches, (a), (b) and (c) (Figure 1) to capture 3 different, yet realistic approaches, in the sense that all 3 are reasonable and possible approaches. Our aim was for one option to be the 'best' option, while the other two options would be 'distractors' or in other words plausible but 'less effective' options (e.g., Shin, Guo & Gierl, 2019). In addition to the likert-scale responses to the three given options, they were also asked three *open-ended questions*: Which of the above approaches are you most likely to use and why? Which of the above approaches would an expert teacher most likely use and why? If your preferred approach is different from (a) to (c), what would that be and why? We also wanted to see if any other plausible approaches would emerge that we hadn't captured in our multiple-choice responses. Such information would help us reflect on the participants' MDC and also help refine items. As mentioned earlier, we piloted the initial design of all 3 survey items with mathematics educators to check for clarity, receive feedback and suggestions for improvements, but also to evaluate if they were perceived the way we intended as designers.

Administration with pre-service teachers: The survey was designed using the Gorilla survey design tool and was administered online during a teaching session. This was to ensure high rates of participation due to the pre-service teachers having a busy work schedule, which may have prevented them from taking the survey at their own time. An *introduction* to the purpose of the survey was shared with the pre-service teachers on a slide. This stated: "We want to find out more about *the competencies that mathematics teachers need to develop to integrate digital technologies into their teaching*. To do this, we are creating and evaluating a self-assessment survey tool for mathematics teachers' MDCs. We expect use of the self-assessment survey tool to stimulate teachers' reflection on practice and build their critical research engagement". We also mentioned that we expected them to spend about *4-5 minutes* per survey item (so, 12-15 minutes on the three MDCT survey items, while the first part of the survey on their beliefs about DT should have taken them up to 15 minutes to complete). After all pre-service teachers finished with the online MDCT survey, as mentioned above, we ran a whole group discussion to invite them to share their reflections, compare each other's responses and give reasons for their approaches, to receive verbal feedback and quite crucially to allow them to recognise their own MDCT. We concluded by asking for their 'take-away' messages from carrying out this survey and for possible suggestions for improvements. As a result, this process stimulated pre-service teachers reflections on their own competencies with regards to using DT in their teaching practice and how their practice may be influenced by the use of DT.

Discussion and concluding remarks

Reflecting upon the qualitative data and the responses to the open-ended survey questions, we start off by discussing the choices for the 'likely' and 'very likely' options the 114 pre-service teachers made with regards to the 3 multiple-choice responses. *For participants who chose (a)* as their likely approach (praise Nick for the loop command and note that Lenny made a mistake with the angles), explanations generally indicated a lack of awareness of the Scratch program, which was either noted explicitly in some occasions or implicitly in others (e.g., believing the 60 degree angle was correct). This indicates a lack of a techno-mathematical discourse (*MDCT1*) regarding Scratch in particular. There was a prioritisation on the maths behind the topic as opposed to how that maths translates to the program i.e., 60 degree interior angle as a property of the triangle versus 120 degree exterior angle as the requirement within the program. Only one participant noted the incorrectness of the 60 degree angle by relating it to bearings. During the interviews, though, we were able to alert the 6 pre-service teachers of this, and we confirmed that at least the 6 we interviewed lacked a techno-mathematical discource with Scratch and therefore did not possess *MDCT1*. For those who indicated an expert teacher would do (c), the emphasis was on allowing students to determine the mistake for themselves and to promote discussion around it. *For participants who chose (b)* as their likely approach (praise Lenny for correct code and note Nick made a mistake with the angles), there was likely to be an emphasis on correcting misconceptions in an efficient way. Only one participant noted the technology, and this was to point out their limited knowledge of it. This again indicates a lack of *MDCT1* posession. Most indicated an expert teacher would do (c), primarily emphasising their greater pedagogical competence in managing class discussions. There was no mention of technology, and the only implicit reference to the maths was that choice (c) allowed the class to address the reasoning behind the mathematical thinking. These observations lead us to think that pre-service teachers seemed to perceive expert teachers possessing mathematical competency over digital competency for teaching. *For participants who chose (c)* as their likely approach (show both methods and discuss pros/cons), a common justification was the benefit of allowing students to discuss and see multiple methods, as well as to correct potential misconceptions. Maths and technology were often mentioned implicitly in this (e.g., their discussion of different methods should naturally entail a focus on the maths and/or the technology), although this was often not explicitly stated. This observation puzzled us as it was difficult to confidently judge whether it indicated possession or lack of *MDCT1*, which led us to agree that the design of our multiple-choice responses in our vignettes may need further refinements, as will be argued further below.

Our first finding regarding the vignette-design approach is that the classroom scenario vignettes provided in the MDCT survey items were appropriate and worked for the purposes of our research study. The feedback we received from mathematics educator colleagues signified the classroom scenarios vignettes had good face validity. The interviews with the 6 pre-service teachers showed that the scenarios were realistic and relatable, but also contained sufficient information for in-depth reasoning about which teaching approach was most appropriate. This was also the case for the Scratch item, despite a lack of familiarity with this software amongst the majority of the pre-service teachers. Our second finding indicates that 'distractors' did not differentiate sufficiently between respondents and therefore the multiple-choice options in our vignettes need to be further developed. The MDCT multiple-choice options were designed in accordance with our experience and knowledge of the mathematics education research literature to reflect 'more developed' and 'less developed' teaching approaches. Very few pre-service teachers selected the 'less developed' teaching approaches as their most likely teaching approach for the MDCT items. Only 12.3% chose approaches (a) or (b) as their most likely approach for the Scratch item, while 87.7% chose approach (c). This result indicates that some of the 'less developed' teaching approach options were simply too easy to dismiss as the 'wrong' answer. In addition, the 'more developed' teaching approach options were too easy to 'agree' with and so did not differentiate enough between respondents.

We have successfully applied a vignette-design approach for a survey regarding the use of technology in mathematics education and in particular MDCT. The vignettes worked for eliciting pre-service teachers' reasoning about how they use DT in the presented scenarios and revealing elements of MDCT. This finding of course is more dependent on the 6 interviews and the open-ended responses in each MDCT survey item. The closed responses from the quantitative data on the MDCT survey items were not as helpful in capturing the more nuanced responses to the vignettes as well as the possession of MDCT. Our future work, therefore, entails capturing teachers' reasoning behind the teaching approach chosen in the vignettes to confidently identify their MDCT, in a study at scale.

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