

Proceedings of the 17th International Conference on Technology in Mathematics Teaching



Editors: Alison Clark-Wilson and Christian Bokhove

St Paul's Girls' School

London, United Kingdom October 21–23, 2025

ABOUT THESE PROCEEDINGS

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Title: Proceedings of the 17th International Conference on Technology in Mathematics Teaching (ICTMT 17)

Year of Publication: 2026

Publisher: University College London Institute of Education

DOI:

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Suggested Citation (APA 7)

Author(s). (2026). Title. In A. Clark-Wilson and C. Bokhove (Eds.), *Proceedings of the 17th International Conference on Technology in Mathematics Teaching*, (pp. XXX-XXX). London, United Kingdom. DOI: 10.14324/000.bk.10223410

The language of the contributions was the responsibility of the authors, and are in English (UK) or English (US),

PAPER AND SCREEN IN INTRODUCING DIGITAL MATHEMATICS ITEMS: A STUDY OF COMPUTER-BASED MATHEMATICS ASSESSMENT IN THE FIFTH GRADE

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In this paper, we study how fifth grade students interact with mathematical items administered in digital format via a computer or tablet. The students belong to a sample of Italian classes that took a digital test in spring 2025 as part of the field trial aimed at evaluating newly designed items within the transition from paper-based to computer-based testing as the mode of assessing mathematical literacy in grade 5. The students were also provided with a sheet of paper as support. After the test, a subgroup of 56 students, randomly drawn from the sample classes, were interviewed in pairs on how they would approach the same items on paper and whether they prefer paper or digital. Using the data from the interviews and the collected support sheets, we examine ways in which students interact with the digital or paper environment to solve the items and advantages and disadvantages of the digital or paper mode of test administration.

Keywords: computer-based testing, paper and pencil, mathematics, primary school

MOVING FROM PAPER-BASED TO COMPUTER-BASED ASSESSMENT OF MATHEMATICS

The international assessment of mathematics at the fourth and eighth grades faced the transition to digital assessment since TIMSS 2019. At that time, about half of the TIMSS countries paved the way for the transition to fully digital assessment in TIMSS 2023 (Mullis *et al.*, 2021). The mathematics part of PISA (Programme for International Student Assessment) also includes digital items, based on the idea that “a level of competency in mathematical literacy in the 21st century includes usage of computers” (OECD, 2013, p. 44). In addition, the PISA framework emphasises that the digital allows for the inclusion of more interactive and authentic items, e.g. with drag-and-drop or real-world data.

While the use of computer-based assessments is becoming increasingly common in mathematics education and other subjects, different assessments are at different stages in this evolution. In Italy, the national assessment of mathematics is computer-based since 2018 for grade 8 (lower secondary) and grade 10, and since 2019 for grade 13 (upper secondary). The feasibility of moving to computer-based testing for grade 5 (end of primary school) is currently under study.

Our study fits into this landscape and focuses on the transition from paper-based to computer-based testing at grade 5 in Italy. This transition implies choices, both at the content and the context level, including the environment to be used for designing the test items and the device to be used for the administration of the test. Because the environment can be more or less interactive or dynamic, and the new device allows for kinds of interaction that are not the same as those with paper and pencil, it is of interest to explore the advantages and disadvantages that students experience in using the computer (or another tool) with respect to paper and pencil when they encounter a digital test, and whether they prefer one medium with respect to the other or they tend or need to use paper at their disposal to support their answers. The current study strives to address these issues, with the aim to contribute to the discussion about the changes and implications demanded by the passage from paper-based to computer-based tests.

THEORETICAL HIGHLIGHTS

A recent study sheds light on the relevance for the students of being “comfortable using the digital functions offered in a test, which is not guaranteed even if they belong to a younger, “digital native” generation.” (Dyrvol & Bergvall, 2023, p. 51). Indeed, it cannot be taken for granted that the use of a digital device is problem-free simply because the students are digital natives (Prensky, 2001) and perceived as possessing digital competence or using digital technology at a larger extent with respect to older generations. On the contrary, some researchers have pointed out that there are no direct differences between digital natives and older generations (see Bennett *et al.*, 2008a; Helsper & Enyon, 2010). This also raises the question of *the extent to which* students need digital skills or *the kind* of digital skills they need to respond to a digital test.

There are a variety of reasons for moving to computer-based assessment. On the one hand, digital resources may provide opportunities to include multimodal resources, such as video explanations, hints or worked out answers, in test items or to manipulate objects, for example through graphing or drawing (Usiskin, 2018), and organize mathematical information in new ways. On the other hand, there are a number of advantages, including: the comparability of results over time; the automatic, thus objective and faster reporting of test results, which offers teachers the possibility of targeted interventions (McClelland & Cuevas, 2020); the inclusion of special features in the test, such as dynamic geometry software (Threlfall *et al.*, 2007); the possibility of time tracking and adaptive testing (Noyes & Garland, 2008); and cost savings. The transition to digital test administration, however, also has some disadvantages, such as fatigue due to reading the screen and the need, for the performance of some items, for a paper medium, which increases the load on the working memory (Russell *et al.*, 2003). The test may also involve fragmented reading, in situations where it is not possible to see a substantial part of an item at a glance and scroll is necessary.

Usiskin (2018) has examined five aspects of mathematics that have roles in mathematics learning (that is, symbolization, representation, deduction, modelling, and algorithms) with respect to the opportunities and challenges they offer when presented in a digital textbook (vs. in a printed textbook). The study suggests two interesting results: “the digital medium is better suited than the paper medium to some work with mathematical modelling and with representations.” (p. 860), but it “seems more poorly suited than the paper medium when working with deduction.” (*ibid.*). In any case, it is relevant to a discourse about digital assessment to keep in mind that “the opportunities provided by digital media are likely to place new demands on students’ ability to read and navigate the digital environment and to work with the digital resources.” (Dyrvol & Bergvall, 2023, p. 52). For example, analysing students’ work with GeoGebra in ordinary teaching, Baccaglini-Frank (2021) has shown that lower-achieving students in mathematics who are used to working with the software outperform high-achieving students who are not used to working with GeoGebra. It may be the case of assessment situations as well.

The literature on comparative studies on paper-based and computer-based tests considers various aspects. Some researchers have studied the familiarity with the environment or the device used for test administration and how it is closely linked to the performance of students completing the test (Russell & Plati, 2001). Others have revealed that computer-based tests are significantly harder than the paper-based test (Bennett *et al.*, 2008b), even if there are contradictory results. Another study on tests in Korean mathematics found higher results on paper-based tests, with a significant difference for females (Hanho, 2014). A more recent experimental research by Davis and colleagues (2021) has investigated which format students prefer to use when responding on tests: 71 participants out of 100 prefer the paper format when contrasted to digital pen or type-written responses, and one of the biggest challenges reported by students in the study with the use of the digital pen was trying to erase and correct their work within the software

used. Comparing items presented in digital and paper format, Lemmo (2021) has shown that equivalence between performances in computer-based and paper-based tests (in terms of right or wrong answers) does not imply equivalence between the *processes* followed by students, and this point is of considerable interest since answering a mathematical question implies especially solution strategies, or how the answer is obtained (process). The processes elicited by items given in different format are also addressed in other studies focused on the validity and comparability of the tests through the analysis of outcomes (e.g., Threlfall *et al.*, 2007). These studies typically consider the transition of items conceived in a paper format into a digital format (migratory approach; minimal changes) or the transformation of original paper items integrating new interactive modalities or affordances (transformative approach; more substantial changes). Grapin and Sayac (2022) offer a comparison between the strategies used by students to solve items that underwent both a migration and a transformation, paying attention to the use of digital technology at home to better understand whether familiarity with the environment can have an effect on the outcomes.

In this study, we focus on some items that were originally constructed for a digital test and were administered with a computer or tablet at grade 5. Students were provided with a sheet of paper as support during the test. Our interest is in how students interact with the digital environment to solve the items and how they use the paper provided. We also want to study advantages and disadvantages of a digital test compared to a paper-based test, as perceived by students.

CONTEXT AND METHOD

The students involved in our study belong to a sample of 240 fifth-grade classes in Italy which took a digital test in the spring of 2025 using a computer or tablet, as part of a field trial to evaluate newly designed items and to try out field operations within the move to computer-based assessment in grade 5. The test consisted of 40 items from the item bank created for the computer-based assessment of mathematics at the end of primary school. The test items cover the three processes of the Mathematics framework: Knowing, Problem Solving, Arguing, and the four mathematical content areas: Numbers, Space and figures, Relationships and functions, Data and predictions.

Seven classes were drawn for this research study. Four classes took the test on the computer and the other three on the tablet. At the end, the support sheets used by the 88 students in five of these seven classes (two of which took the test on the computer and three on the tablet) were collected. Four pairs of students were randomly drawn from each class and interviewed immediately after the test in digital mode, for a total of 56 interviewees. The interview was conducted by the second author with each pair of students tackling with pen and paper a subset of the items already addressed in the digital test. A total of 8 multiple-choice items were chosen for the interviews, and each pair tackled 4 of them. Each item was therefore tackled by 14 pairs. The eight items were selected to cover all content areas and processes. They include reasoning about: polygons with given characteristics; axes of symmetry of a given polygon; length of the sides of a regular polygon; the fraction represented in a given figure; space-time relationships in context; figural patterns; positioning a number on a given number line; completing a given graph. In the interview, each pair of students was asked to address together the four assigned items, which were simply migrated from screen to paper. In a first phase, the students were specifically asked to solve the item, arguing and justifying their answer, and invited to converse, write on the item text and freely use the space available on paper. In a second phase, they were asked to reflect item by item on the modes of delivery. Examples of questions are the following: “Do you prefer to address this item on paper or on the screen? Why?”, “Which mode are you surer to answer correctly or to reason better? Why?”.

Data used for the analysis consist of the written productions in the support sheets and the answers given during the interview. The analysis is mainly qualitative, but makes use of the frequency with which similar

answers occur. As an example, we will also consider the interaction with a specific geometric question that depicts a concave octagon and asks you to identify the number of its axes of symmetry from four options. The choice is based on the fact that symmetry is a central topic of mathematical learning at primary school, so it is of interest whether the solution processes and approaches may be different depending on the mode of test administration, i.e. paper or digital.

Research questions

According to our commitments, the research questions we strive to investigate are as follows:

- What are the advantages and disadvantages of taking a test in paper or digital mode?
- With regard to mathematics items in particular, how do students express and describe their preferred approach and what reasons do they give? Do they prefer to imagine or write?
- When taking the digital test, do students use the support sheet? If yes, how do they use it? How do they describe the potential and limitations of the support sheet?

Furthermore, with reference to the specific geometric question:

- What ideas do students have about symmetry? What elements do they identify as axes of symmetry? Is there consistency between what they say and the axes they identify?
- After the digital test, how do students describe the process they followed in solving the item?
- What do they state regarding the specific item and the delivery mode?

RESULTS

In this section, we present the results of our analysis. Through the interview, we can appreciate a variety of aspects, some more general, related to advantages and disadvantages of the computer-based versus paper-based delivery mode, others more specific, related to the resolution of particular mathematics items. We will examine them separately and quote some phrases from the interviews (*in italics*), which are intended not to express the number of voices in favour of one or the other mode, but to contribute to a better understanding of the arguments. In general, it can be observed that arguments in favour of the digital test have been put forward more frequently than those in favour of the paper-based test. In fact, in 156 cases, a reasoned preference for the use of a device was expressed, in 87 cases an argument was put forward in favour of there being no difference between the modes, and in 78 cases an argument was put forward in favour of using paper. These numbers count not only each student's opinion once, but each supporting argument, as students commented on this topic several times during the interview. We summarise the results according to three different lines of thought, which concern the advantages and disadvantages of taking a test in one mode or another; interactions and the use of the support sheet; and the geometric question.

Advantages and disadvantages in the two modes

46 times in the interview, students state that they saw no substantial difference between the two modes of delivery, since in both cases they could use pen and paper to write. Examples of this include expressions such as: *"We also have the sheet of paper to hand"* or *"You always save yourself"* thanks to the support sheet, even if you are in front of the screen. In addition, 41 respondents stated that it is not necessary to write in order to answer the items during the interview: *"I think better in my head than I do when writing"*, *"I just imagine"*. A large group of students (34) note that it is essential to interact with the text of the item by making marks, for various reasons and in various ways that we will discuss later. These arguments

therefore weigh in favour of administering the test on paper (e.g., *“Let’s say it was easier because you could still make marks”*).

Specific characteristics of the devices recur 33 times, this time in support of the preference for digital mode. These include the ability to zoom in on certain parts of the item using the +/- button available on the platform or by pinching the screen with your fingers: *“You can look closer because you can zoom in on the image”*. Some comments concern the possibilities offered by the mouse, such as: pointing to keep track of where you are with the count or moving it quickly to take advantage of the persistence of the image on the retina; or dragging an image, without releasing it, to see the image in its original position and the same image translated and held suspended in transparency. Other aspects concern the possibility of immediately checking the items that have already been answered and correcting those that you want to review (*“If you skip an item on paper, you have to write down which one, while the eye on the tablet helped me a lot”*); and to see the colours clearly, to zoom in to see the entire item, to adjust the brightness. One recurring aspect against the digital test is due to uncertainty in using the device (19 times). The risks are mentioned, for example: *“If you count with your finger on the tablet, there is a risk of opening something, moving something”*; *“There is a risk that my test will be cancelled”*, but also habits: *“I think better on paper because I am used to it”*.

The following aspects are taken into account less frequently:

- time management, considered both by those who prefer to take the test on paper (*“Paper is faster”*, *“You have to wait to press”*) and, to a greater extent, by those who prefer the digital mode (*“It’s faster on the screen, just touch it”*, *“Just click”*);
- the dual advantage of the digital mode of offering a clean item, on which it is not possible to make marks (*“On paper, if you make a mistake, you ruin everything”*, *“So paper is more confusing, and therefore you are more confused”*), and of reviewing the answer selection (*“Just press the other one”* – the choice is immediate; *“You can try”*, *“I’ve marked it, but you can correct it later”* – an exploratory approach is encouraged);
- better readability and less effort in answering items when reading on paper (*“Paper is less tiring”*, *“In can see better on paper”*, *“I read faster”*);
- emotions and engagement, in favour of the digital mode (*“It’s fun on the tablet”*, *“A child is enthusiastic about the computer”*).

Interactions and use of the support sheet

With regard to the type of interaction that students have with particular items presented on screen or on paper, there are a number of specific observations concerning:

- the fact that it is often sufficient to imagine, regardless of the mode;
- the possibility of physically interacting with the text of the item when it is presented on paper;
- the different ways of using the support sheet when answering items presented on the screen.

To address the last point, we not only use the interview responses, but also examine the content of the support sheets that students used during the test. Among the interviewees, many stated that they did not need a pen to solve the interview items and repeatedly referred to calculation and drawing, arguing that mental calculation is sufficient and more efficient than written calculation, that the calculations required were *“easy”* and *“with small numbers”*, or that imagining straight lines and paper folds is sufficient to answer the geometric questions (*“Just look”*, *“Draw in my mind”*). In short, students believe that the support sheet

is mainly used for calculation and representation of figures. Analysis of the 88 written sheets collected in the classes confirms this.

Of the 88 students, 76 used the sheet and 61 of them used it extensively, to solve at least five of the 40 items. The main use was for written calculations, predominantly addition, multiplication and division with natural numbers performed using standard algorithms or series of calculations in rows or columns, as in this example: $8+16=24-12=12$. Then there are the figures: polygons, which are drawn to count certain elements or to study their properties, stylised drawings that schematise situations to be manipulated to calculate a probability, and sequences of figures to look for regularities. Some students used the sheet to record partial results, data or answers. Other elements present are arithmetic or temporal patterns, sequences of natural numbers to reason about direct proportionality, equivalences of capacity, or diagrams listing multiples and submultiples.

On the other hand, interactions with the text of the items written on paper emerge in particular because students feel the need to draw on the figure or graph or, being able to do so, feel facilitated in solving the task. They draw for various reasons. Drawing is seen as useful for understanding and reasoning: *"You can make arguments that you wouldn't otherwise be able to make..."*, *"To show how many there were or to help you understand how you thought of doing it"*, to reduce the load on your working memory: *"With a tablet you have to be able to keep in mind all the lines you need to draw, whereas on paper it's easier"*, *"You can write wherever you want"*, and to insert information from the text onto the figures, linking the registers. One student who states *"it might take a little longer"* expresses that writing on the text of the item helps to get closer to the solution through 'slow thinking', unlike in the digital mode. Many students say that writing on a piece of paper is better than having to shift their attention from the screen to the paper: *"You take your eyes off the image to write on the paper"*, *"At least you always have the question written here"*.

Other uses of the support sheet have to do with: pointing on the sheet with your finger or pen to make counting easier or to fix a particular point (*"It seems easier to count"*, *"For me, it's better here on the sheet because you can also touch it"*), making a note between the lines of the item text (*"I didn't use calculations but I wrote something on the item"*), ticking boxes, for example, to exclude alternatives, activating control processes still related to counting or choosing a solution procedure (*"I am sure those are the only ones and there are no others"*, *"Maybe we need to try more calculations and maybe what you said before was right, but I don't remember"*).

The case of a geometric question on symmetry

In this section, we focus on the geometric question that asks students to identify the number of axes of symmetry in a given concave octagon. This focus can help us better understand students' ideas about symmetry and the processes or strategies they used to tackle the task, including in relation to the test format. Most respondents said they looked for the axes of symmetry without relying on the support sheet, but mainly *"in their head"*, *"by eye"*, *"by thinking"* or *"by imagining"*, while some said *"with my finger so I could see"*, moving the mouse quickly. Only two students drew the polygon on paper and three reported that they would have preferred to be able to draw directly on the figure.

17 out of 28 students gave a correct answer to the item presented in digital form. Of the other 11, 10 students identified more axes of symmetry than were actually present. Among those who answered correctly, when asked to justify their choice, some implicitly referred to the "coincidence" of the two parts obtained by folding the figure along the axis, while others referred only to the concept of half (although there are ways to divide the polygon in half, for example using the diagonals, which do not make use of the axes of symmetry). Among those who answered incorrectly, students defined the axis of symmetry as: a line that divides the figure in half; a dotted line; a line that divides the figure into triangles; a line that connects

the vertices, thus as a diagonal of the polygon; or a line corresponding to the height of the figure. An interesting note concerns the sketches of axes of symmetry made during the interview: they are not always consistent with the ideas expressed orally. We can assume that this depends on the students' view of the axis of symmetry as a segment rather than a straight line, which could explain to some extent the misconceptions demonstrated by students.

Many questions remain unexplored regarding the differences or connections between digital and paper-based test administration, offering opportunities for further investigation. We believe that this preliminary study provides an initial reflection on how students may perceive, process and approach mathematical tasks administered digitally and how attention is needed in the design of questions aimed at assessing mathematical competence.

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