The use of spreadsheet tools in assessment: an instrumented technique perspective

MATTIAS WINNBERG

A challenge in computer-based assessment, especially when introducing specific digital tools, is balancing mathematics assessment with students' computer skills. This exploratory qualitative study aims to investigate aspects of student-tool-interaction, essential to consider when designing digital tools for assessment. Eight 15-year-old students worked in pairs with three digital test items employing interactive spreadsheet tools, followed by semi-structured interviews. The combined analysis of observations of students' interactions with the items and the interviews indicates difficulties in using basic spreadsheet functions – despite their conceptual understanding of the tools. The main implications of the findings emphasize the importance of integrating digital tools into learning situations before assessment, and not taking basic tool-related techniques for granted.

In recent decades, a large body of research has focused on the paradigm shift from paper-based assessment to computer-based assessment (see e.g. Bryant, 2017; Drijvers, 2018; Hoyles & Noss, 2003; Mills & Breithaupt, 2016; Way et al., 2016). This shift is justified concerning the dominant use of technology in society which in educational contexts impacts the use of technology, not only in teaching and learning, but also in assessment. The argument is that assessment must also follow this development (Beller, 2013; Bennett, 2002). However, implementing such a paradigm shift requires the consideration of several aspects. For instance, the transfer from paper-based assessment may be guided by validity concerns (Way et al., 2016). This relates to whether the mathematical construct at focus is being affected, and whether new modes of assessment introduce construct-irrelevant variance. Some scholars emphasize that construct underrepresentation and construct-irrelevant variance

---

Mattias Winnberg
Stockholm University

Winnberg, M. (2025). The use of spreadsheet tools in assessment: an instrumented technique perspective. *Nordic Studies in Mathematics Education*, 30 (1), 83–102.

generally threaten the validity of test score interpretations (see e.g. Messick, 1989). In the context of digital assessment in mathematics, this concerns whether a test assesses students' mathematical competencies, or unintentionally, their computer skills.

The increasing use of technology in education also raises vital issues in assessing mathematical competencies (Stacey & Wiliam, 2013). For instance, without the "burden" of routine calculations the assessment activities might focus on broader mathematical competencies, for example, problem-solving, reasoning, and mathematical modeling (Stacey & Wiliam, 2013; Yerushalmy et al., 2017). However, for assessment results to be valid and interpretable, the context of assessment should not significantly differ from the context of learning (Sangwin, 2013; Stacey & Wiliam, 2013). Therefore, whenever digital tools are used in assessment situations – such as the spreadsheet tools reported on in this study – it is crucial that the assessment situations align with the competencies that students have developed in learning situations. While acknowledging the relevance of focusing on mathematical competencies, in this paper, however, attention is directed toward students' digital competencies in using digital tools for solving mathematical problems – an aspect that remains underexplored in research.

Aim and research question

This study aims to investigate aspects of student-tool-interaction, essential to consider when designing digital tools for assessment. A justification behind this aim is to shed light on some essential issues associated with introducing digital tools in assessment situations. These concerns may differ for test developers, teachers, and students. For example, even though digital tools have been around for several decades, a significant proportion of students enrolling in universities are unable to make productive use of such tools, for instance, spreadsheet programs (Chong et al., 2015). However, numerous digital tools and item formats are already being applied in assessment situations. To demarcate this study, the focus will be on students' work with digital tools using spreadsheet functions. This focus addresses an identified research gap in using spreadsheet tools in assessment, which is further discussed in the background section.

With the above as a backdrop, the study is framed by the following research question:

> What student-tool-interactions can we identify, and need to be considered when designing spreadsheet tools for assessment?

Background

In mathematics education, there is a considerable body of literature on the use of spreadsheet tools in teaching, especially concerning learning algebra (e.g. Dettori et al., 2002; Haspekian, 2005, 2014; Sutherland & Rojano, 1993; Tabach et al., 2008; Topcu, 2011). The findings generally suggest a significant positive relationship between spreadsheet use and learning outcomes in algebra. The potential of using spreadsheet tools in education is also linked to interactive features, computational abilities, and the capacity to represent data in various forms (Haspekian, 2014). However, since spreadsheet programs were not initially developed for educational purposes (Haspekian, 2014), nor are they adapted for mathematical learning, using spreadsheet tools in assessment situations may come with particular consequences for students. One relevant concern is how using specific spreadsheet functioning tools will help students solve the mathematical tasks at hand.

Rationale for studying spreadsheet tools in assessment situations

When studying the use of technology in mathematics education, various research studies apply an instrumental approach (see e.g. Buteau et al., 2020; Drijvers et al., 2013; Drijvers & Gravemeijer, 2005; Haspekian, 2005; Misfeldt & Jankvist, 2018). Generally, these studies center on teachers' instrumental orchestration (Guin & Trouche, 2002; Trouche, 2004), or on

students' interaction with technology and the development of instrumental genesis – wherein an artifact develops into an instrument – a psychological construct comprising an artifact and mental schemes. In this context, Artigue's (2002) seminal work on instrumentation theory represents a significant reference, particularly in studying mathematics learning within technological environments. Other examples of technology use in studies applying an instrumental approach include, for example, spreadsheet tools used for algebra learning (Haspekian, 2005), computer programming employed as an instrument for mathematical work (Buteau et al., 2020), and Geometer's Sketchpad used as a tool for visualizing derivatives (Ndlovu et al., 2011).

Previous studies have explored the use of spreadsheet tools in various educational contexts – in relation to learning algebra (e.g. Haspekian, 2005; Tabach et al., 2008), concerning computational thinking when learning statistics (van Borkulo et al., 2023), and about the learning of financial mathematics (e.g. Chong et al., 2015; Özkale & Özdemir Erdoğan, 2021). However, to the best of my knowledge, there is a lack of research focusing on spreadsheet tools within the assessment context. Consequently, the presented study intends to contribute to a more comprehensive discussion about using spreadsheet tools, especially concerning students' digital competencies. In this study, the students' work with spreadsheet tool items was analyzed using the concepts of instrumented techniques, instrumented action schemes, and instrumentation – derived from an instrumental approach.

Theoretical framing: an instrumental approach

The theoretical underpinning of an instrumental approach allows the researcher to explore the emerging and intertwined relationship between digital tool use and mathematical thinking (Drijvers et al., 2010), and mathematical concepts (Haspekian & Fluckiger, 2022). The theoretical foundations supporting an instrumental approach build on Vygotskij's (1978) theories about learning mediated by tools, and were subsequently developed from cognitive ergonomics (Rabardel, 2002), where the development of schemes is a central aspect (Drijvers & Gravemeijer, 2005).

From an instrumental perspective, an object used as a tool is referred to as an artifact (Rabardel, 2002). Moreover, some key distinctions exist between an artifact's and an instrument's psychological construct. An instrument is conceptualized as something more than an artifact; it also includes the user's cognitive structure when performing a particular activity with the artifact (Rabardel, 2002). This relates to using the tool according to one's needs, and simultaneously recognizing the tool's possibilities and constraints (later referred to as instrumentalization and instrumentation). The digital tool (i.e. the spreadsheet component) may, therefore, within this instrumental conceptualization, be developed into an instrument in the hands of the students. This process, referred to as instrumental genesis, involves the artifact and schemas of use.

Instrumental genesis can be traced back to Verillon and Rabardel (1995). According to them, the psychological construct of an instrument is formed by an artifact – a symbolic or material object used by a subject with a clear purpose – together with associated utilization schemes within the subject. When applying an instrumental perspective, some researchers (e.g. Drijvers & Gravemeijer, 2005; Trouche, 2005) use the terms usage schemes and instrumented action schemes, when referring to related utilization schemes. A key point within the instrumental approach is that an instrument is not something given. Instead, an instrument needs to be constructed by the subject, developing utilization schemes in the process of instrumental genesis (Verillon & Rabardel, 1995).

The complex process of instrumental genesis is simultaneously constituted of two bilateral progressions. One process is directed toward the object (instrumentalization), whereas the other process is directed toward the subject (instrumentation) (see e.g. Artigue, 2002; Rabardel, 2002; Thomas, 2009; Trouche, 2005). Instrumentalization is related to the evolution of artifactual components of the instrument and how a subject might adapt the artifact's functions for specific uses (Rabardel, 2002). This process is guided by the subject's knowledge about using and shaping the artifact (Drijvers et al., 2013). On the other hand, instrumentation is associated with the advent of utilization schemes and instrument-mediated actions, and how the subject adapts to the artifact (Rabardel, 2002). The continuing development of utilization schemes will gradually form instrumented techniques, enabling the subject to respond to certain activities (Artigue, 2002).

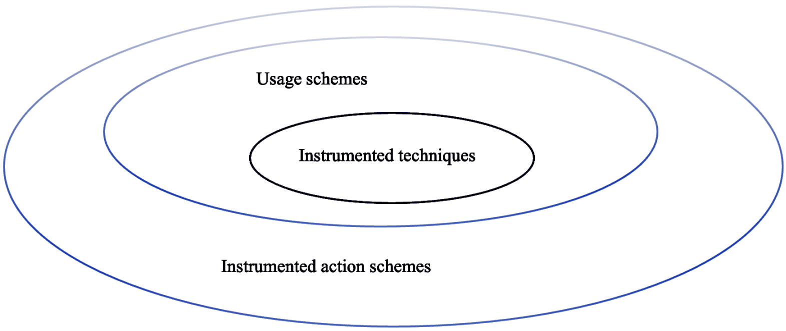


Figure 1. *The building blocks of instrumental genesis*
Note. In this conceptual model, instrumented techniques, usage schemes, and instrumented action schemes are interconnected concepts. Instrumented techniques represent the technical and visible components within mental usage schemes. These elementary usage schemes serve as foundational elements to develop more complex instrumented action schemes.

When referring to utilization schemes, I follow the reasoning of Drijvers and Gravemeijer (2005), who build upon the work of Rabardel (1995), Guin and Trouche (2002), and Trouche (2000). Corresponding schemes are accordingly categorized into usage schemes and instrumented action schemes. Usage schemes are fundamental schemes directly related to the artifact, for example, the sorting function of the spreadsheet, or the selection of numerous cells in the spreadsheet tool. A skilled user may apply a select scheme directly and swiftly, while an inexperienced user must simultaneously manage technical and conceptual aspects. The second scheme category, instrumented action schemes – developed from elementary usage schemes – is conceptualized as a stable mental organization where technical and conceptual aspects interact, see figure 1. The key elements in an instrumented action scheme (see below) are technical and conceptual milestones towards instrumental genesis – wherein an instrument is produced from the artifact by means of related usage schemes. Concerning the items used in this study (see appendices A–C), instrumented action schemes involve technical skills, for example, the selection of cells, but also the mental capability to imagine what the calculation program can accomplish with the data in the cells concerning the specific task at hand.

One noticeable challenge with schemes is that mental features can never be observed directly. Hence, Drijvers and Gravemeijer (2005) use instrumented techniques (Artigue, 2002), which are understood as the manifest and observable aspects of an instrumented action scheme (Trouche, 2005). Therefore, the examination of instrumented techniques may be used as a gateway for analyzing students' instrumental genesis (Drijvers & Gravemeijer, 2005). The following sections will present hypothesized instrumented techniques (expected techniques from productive tool use), enacted instrumented techniques (what the students did), usage schemes, and instrumented action schemes. Reconsidering the research question about what interactions we can identify, framed by an instrumental approach, these interactions are thus the enacted instrumented techniques, the observable facets of an instrumented action scheme. To further elaborate on what is needed to be considered when introducing spreadsheet items, the key idea is to focus on instrumentation. In this process, the students recognize the affordances and constraints of the spreadsheet tool.

Methodology

The data for this exploratory qualitative study were collected in 2022 at a secondary school in the Stockholm region of Sweden. The school offers a special focus on mathematics and the students were able to participate in the first mathematics course at the upper secondary school level one year ahead of the usual schedule.

Sample and sampling

One of the mathematics teachers at this school helped recruit the students based on their interest in participating. The teacher described them as highly motivated mathematics students who were familiar with digital tools (e.g. graphic calculators, GeoGebra, and LaTeX editors). At times, the teacher also demonstrated spreadsheet programs. The participants ($n = 8$) were five boys and three girls from Swedish 9th grade (15-year-old students). The students' most recent grades in mathematics ranged between C and A[1].

Data collection approach

Data were collected with the students in pairs at the school. The students were informed about the research purpose, and that participation was voluntary, and each signed informed consent forms. The data consisted of video recordings of students working with three items (where the researcher was an observer), including screen captures with audio, and the succeeding interviews were recorded on a digital audio recorder. While the students worked with the three items, they also had access to note paper, a handheld calculator, and a mathematics formula sheet. The students were not restricted by a time limit and spent about 15 minutes engaging with the three items. The semi-structured interviews took approximately 20 minutes for each of the four groups, and were performed immediately after each group's working with the three items. An interview guide included questions about using digital tools in mathematics classes, students' experiences of the three items, how they tackled the problems, and whether similar test items might present possibilities or constraints.

Data analysis approach

The data analysis was performed in two stages, as summarized in table 1. In stage 1, before data collection, the hypothesized instrumented action schemes were formulated, informed by the instrumental genesis theory. Subsequently, the screen and video recordings and the interviews were transcribed verbatim, with no focus on pausing length or speech tone. After transcribing, the students' interactions with the items were initially coded into two broad categories: hypothesized instrumented techniques, and enacted instrumented techniques. After that, the hypothesized instrumented action schemes were compared with the enacted instrumented action schemes, and codes for the instrumentation process were developed (see table 2). This process is key to understanding instrumental genesis by identifying the constraints and affordances generated by the instrumented work (Artigue, 2002).

In stage 2, a content analysis (see e.g. Brinkmann & Kvale, 2018) was performed, where the hypothesized and enacted instrumented techniques, and how the opportunities and constraints of the spreadsheet tool affected students' performance (instrumentation, see table 2), were compared across the four groups. An overview of data analysis is presented in table 1.

The point of departure for the analysis – of the students' interactions with a digital tool along with the subsequent interviews – is the assumption that the spreadsheet tool is considered to be an instrument whenever there is a meaningful relationship between a student and the

Table 1. *Overview of data analysis*

Stage and objective	Outline	Comment
Stage 1. Qualitative data analysis Identification of students' instrumented action schemes	Step 1 (Before data collection). Preformulating hypothesized instrumented action schemes	The hypothesized instrumented action schemes include the A.–L. key elements
	Step 2. Observing students' work (video) and interviews (audio)	Transcription of data
	Step 3. Categorizing data from step 2 by using instrumented techniques and hypothesized instrumentation action schemes. Developing enacted instrumented action schemes and creating codes for the instrumentation process (see table 2)	The hypothesized instrumented action schemes are compared with the data. Discrepancies inform the formation of enacted instrumented action schemes
Stage 2. Interpretive content analysis Identification of overall patterns	Identifying overall patterns in the enacted instrumented action schemes and in the processes of instrumentation across the four groups of students	The codes for the instrumentation process are presented in table 2

Table 2. *Instrumentation coding framework*

Item	Usage scheme	Enacted instrumented action scheme	Code for instrumentation	Examples
1 Smartphone use	Sorting scheme	Same as the hypothesized instrumented action scheme	Recognition of tool possibilities	Recognition of the sorting function
2 Charity gala	Selecting scheme	Not the technical key elements (F & H)	Recognition of tool possibilities	Recognition of the imagined possibility of using a sum and mean formula
			Recognition of tool constraints	Students' recognition of their inability to select multiple cells
			Adaptation to tool constraints	Abandoning the spreadsheet tool and using a handheld calculator; writing notes in the spreadsheet
3 Interest cost	Formula scheme	Not the technical key elements (J, K & L)	Recognition of tool possibilities	Recognition of the imagined possibility of using a formula and a fill-down function
	Filling down scheme		Recognition of tool constraints	Students' recognition of their inability to select multiple cells
	Selecting scheme		Adaptation to tool constraints	Filling in the spreadsheet manually, using a handheld calculator

Note. The letters (e.g. F & H) represent key elements in the hypothesized instrumented action schemes for the items used in this study; see the next section. The selection of the above usage schemes is based on the criterion that they should include a basic scheme directly related to the artifact's function, such as sorting data. The codes for instrumentation, for example, students' recognition of tool possibilities, are instances where students recognize the tool's characteristics for a specific task and how the tool influences students' performance. Examples of students' utterances related to the usage schemes and the instrumentation process, which also were used to identify the presented usage schemes and instrumentation codes, are provided in the results section.

spreadsheet to productively work with a presented item (Drijvers & Gravemeijer, 2005). This relationship involves the observable instrumented techniques, usage schemes, and instrumented action schemes. As stated previously, the instrumental genesis process is not directly detectable. Thus, it is argued that the enacted instrumented techniques accompanied by the video and interview data (significant moments where students recognize opportunities and constraints of the digital tool; instrumentation) are the gateway to investigating instrumental genesis.

Examples from the transcripts are used in the results section to highlight instances where usage schemes and instrumented action schemes related to the artifact were (or were not) developed to produce an instrument. This analysis mainly focuses on the instrumentation process of instrumental genesis since the students had limited opportunities to adapt the spreadsheet tool to their needs (instrumentalization). The presented study is not about ignoring the instrumentalization process of instrumental genesis. Instead, due to the spreadsheet tools' limited adaptation affordances, the instrumentation process may be the dominant one (Rabardel, 2002). The author translated the episodes from Swedish to English, and the students were given pseudonyms.

The items in the study

The three items (see appendix A–C): 1 Smartphone use, 2 Money raised at a charity gala, and 3 Interest cost for a loan, are described below in the same sequence they appeared in the assessment platform. The items were developed for this study, together with test developers, to investigate instrumented techniques and related usage schemes concerning the items with a spreadsheet component. Following Drijvers and Gravemeijer (2005), key elements in a hypothesized instrumented action scheme for the three items were suggested, i.e. how an instrumented action scheme may develop from successful instrumental genesis. The author proposed, a priori, the key elements in a hypothesized instrumented action scheme (A–L, see below) for the three items, which were also validated through discussions with colleagues working on test development. The first item requires basic instrumented techniques and usage schemes when employing a sorting function. In the two succeeding items, the anticipated instrumented techniques and usage schemes are more sophisticated, since the students could work with formulas in the spreadsheet. Also, the students were expected to select multiple cells to exploit the full potential of the spreadsheet tool.

Item 1 (see appendix A), is a translation of a released PISA item (OECD, 2018) adapted for the assessment platform used in this study. This item was included in the study because of its potential to be a suitable start item that excluded advanced instrumented techniques. The key elements in a hypothesized instrumented action scheme for this item are proposed to be the following.

A Know that the words largest/least are associated with the highest/lowest number in the spreadsheet table column.

B Understand the concepts of median, number, and proportion.

C Understand that the numbers in the spreadsheet columns are sorted in ascending order when the sorting buttons are pushed (related to the sorting usage scheme).

D Being able to make relevant comparisons of column data.

All the key elements (A–D) in this hypothesized instrumented action scheme have conceptual characters. The key element C also has a technical (and observable) character (pushing buttons).

For item 2 (see appendix B), the students are prompted to calculate the total and the average donations. In the spreadsheet tool it is possible to create a formula, or to select multiple cells generating the sum and mean automatically. For example, when the cells B3–B22 are selected, the sum and mean values are presented at the bottom of the spreadsheet tool – a functionality similar to Excel and Google Sheets. The study included this item to investigate students' ability to select multiple cells in a spreadsheet tool simultaneously. The following key elements in a hypothesized instrumented action scheme for this item are suggested.

E Understand that the total is the sum of the donations presented in cells B3–B22.

F Being able to select the cells B3–B22 and identify the presented sum, or being able to use a formula [=SUM(B3:B22)], e.g. in cell B23 (related to selecting usage scheme).

G Understand the concept of mean (on average).

H Being able to select the cells B3–B22 and identify the presented average, or being able to use a formula [=AVERAGE(B3:B22)], e.g. in cell B23.

The key elements E and G are conceptual, whereas F and H are technical (and observable).

For item 3 (see appendix C), the students are first encouraged to "fill down" the interest cost for each of the 20 months in column C. Thereafter, the total interest cost is calculated and entered in the box below the spreadsheet tool. This item was included in the study to investigate students' capability to use formulas. Key elements in a hypothesized instrumented action scheme for this item are proposed to be the following.

I Understand the concept of monthly interest of 2 %.

J Understand that the interest for the first month can be calculated using a formula [=B2*0.02].

K Being able to fill this formula down for the 20 months.

L Being able to select the cells C2:C21 and identify the presented sum, or being able to use a formula, e.g. in cell C22 [=SUM(C2:C21)].

The key element I has a conceptual aspect, whereas K and L are technical (and observable). J, it is argued, is both conceptual and technical (and observable) since the student first needs to understand what factor to multiply by, and then technically enter a formula in the spreadsheet tool.

Results

The first section presents the observed interactions (a summary of the enacted instrumented techniques, compared to the hypothesized instrumented techniques), and the second section presents data from video and interview recordings associated with usage schemes and the instrumentation process.

Observed instrumented techniques

Regarding the students' interactions with the spreadsheet tool, the results from the observations are presented in table 3.

As shown in table 3, the instrumented technique to sort data (by pushing sort buttons) was observed for item 1. In two groups, the students initially had some problems figuring out how the sorting function operated. This development of a sorting usage scheme was related to how the spreadsheet data were manipulated when the sorting buttons were pushed; whether the entire spreadsheet was sorted, or just the column in question.

The two subsequent items were more challenging for the students, considering the implementation of hypothesized instrumented techniques. Video and screen recordings showed that scrolling in the spreadsheet component caused issues for students due to high sensitivity compared to scrolling the entire item.

Table 3. *Summary of the extent to which instrumented techniques were observed in students' work with the three items*

Observed instrumented techniques	Items		
	1 Smartphone use	2 Charity gala	3 Interest cost
Sort data (C)	Yes, by pushing sorting buttons, some problems	No	No
Scroll spreadsheet	Not required	Some problems	Some problems
Select cells (F,H,L)	Not required	Some cells but not all, or to many cells	No
Use formula (F,H,J)	Not required	Yes, but formula included the column heading	Yes, but formula included a syntax error
Fill down formula (K)	Not required	Not required	No

Note. The letters (e.g. C) are the observable key elements in a hypothesized instrumental action scheme.

Items 2 and 3 involve the hypothesized instrumented technique for selecting multiple cells simultaneously. Any of the four groups did not successfully perform this select technique. In one of the groups, the students managed to select some of the cells in one column. However, this task was too demanding when they needed to scroll down in the spreadsheet tool to select the out-of-screen cells. In another group, the students selected all the cells in one column by pressing the column heading. Unfortunately, when they later used the auto-summation formula, they assumed this did not work due to the inclusion of the heading text. All the students found ways around the problem of being unable to select multiple cells, for instance, by using the calculator or writing memory notes in the spreadsheet while doing the sum together in their heads. For item 3, none of the groups tried to select several cells simultaneously, possibly due to the previous shortcomings.

Two groups considered using a formula to calculate the interest costs for a given month for item 3. This instrumented technique was not applied productively by the students since they did not know how to employ the formula in the spreadsheet. One of the groups tried to write the formula C1 + C2 = (syntax error) in cell G2 but realized that this operation would only produce text in the spreadsheet tool. None of the groups tried to fill down a formula for the cells below.

Usage schemes and instrumentation

It is proposed (see previos section) that an instrumented action scheme related to item 1 should include a conceptual understanding of some mathematical concepts (median, number, and proportion), an understanding of how the spreadsheet is manipulated via the sorting buttons, and the capability to make relevant comparisons of data. The following episode from the video recordings is used as an example to illustrate instrumentation (in this case, the students recognizing the possibilities of the sorting function). It describes the situation when Anna and Tim are working with the second unit in item 1.

Anna: So, if we press the buttons land, population ... [presses button A, then B]

Tim: And then Smartphone user, million, then it is false [presses button A, then C]

Anna: Yes! Because it is Bangladesh. OK, now I get it!

In the subsequent interviews, the students described, once they understood how the sorting function operated, how they found it quite straightforward to manage the sorting tool as a means to answer the questions. As previously argued, this manifest instrumented technique (to push sorting buttons) along with conceptual understanding, is conceptualized as indicators that the sorting function became part of the students' mental scheme in the process towards instrumental genesis.

The suggested instrumented action scheme for item 2 involves an understanding of what the spreadsheet data represents and the instrumented technique for selecting relevant cells or being able to use a formula. The following transcript passage from an interview illustrates the discussion between Hugo and Emil when describing how they tried (but failed) to select multiple cells.

Hugo: We kind of tried to skip the calculator and wanted to do this select thing.

Emil: Exactly!

Hugo: But it was a little problematic to do it!

Emil: Actually, we knew what we had to do, but it was a little bit tricky.

In the above episode, the students conceptually recognized what they must execute (the select usage scheme) to sum up the donations. However, if the spreadsheet is to be considered an instrument in the hands of the students, the usage scheme for selecting several cells should also be present. In the other groups, the students similarly demonstrated an understanding of the potential functionality offered by the spreadsheet tool. They expressed an awareness of the possibility of selecting multiple cells for summation, as evidenced by remarks such as: ”It should be possible to select all of these!”. Additionally, they recognized the utility of summing donations, as indicated by the statement: ”If only there were a function that could add this up!”. During the subsequent interviews, one of the students expressed frustration over the inability to use the spreadsheet tool for calculating the sum of donations. An example of how the tool influenced student performance (instrumentation) was observed when students abandoned the spreadsheet tool and instead used a calculator. In essence, when working with item 2, students displayed the capacity for conceptualizing how to employ the spreadsheet tool for calculating the sum and means of donations. They seemed to grasp the conceptual aspects of an instrumented action scheme for item 2 (the key elements E and G). However, they simultaneously encountered difficulties with the technical aspects of the select usage scheme (key elements F and H) as they struggled to execute the instrumented technique of selecting multiple cells in the spreadsheet.

When working with item 3, all four groups understood the interest rate concept (key element I). Three of the groups recognized the possibility of using a formula. For example, when Anna and Tim after filling in the interest costs manually they tried (but failed) to select the cells C2–C21. In this situation, Tim argued that it should be possible to select several cells in the spreadsheet tool: "We need to be able to select these cells somehow! I've seen my dad do this 100 times!". In Hugo and Emil's group, the students tried to implement a formula. However, they failed due to syntax problems. In Elsa and Sofia's group, the students recognized the possibility of using a formula, as indicated by the following statement from Elsa: "There should be an insert function! Can't we just write 0.02 times the numbers under B?". In this group, the students later abandoned the spreadsheet tool, and instead used the handheld calculator for calculating the interest costs, thereafter calculating the sum with the calculator. The passage below from the interviews follows up a statement from Elsa about the challenge associated with using a formula.

Int.: One of you said: "What if there is a function that we could insert, this will take forever otherwise".

Sofia: It would have taken a long time to write everything, but it would be quick since there were two of us.

Int.: [asking Elsa] I think you said: "Can we write 0.02 times C". Could you please explain what you were thinking then?

Elsa: I was thinking that you should get 2 %, 0.02, and all the numbers under C; it was the money, so I was thinking 0.02 and then times the numbers, and then get the sum of all the answers.

The above episode is suggested to reveal Elsa's conceptual understanding of what the digital tool might accomplish, in this case, the possibility of using a formula and a fill-down function. However, an instrument must have been developed from the spreadsheet tool and related usage schemes to argue for instrumental genesis. But in this situation, the technical aspects of instrumental genesis were missing. Elsa understood the potential of the spreadsheet tool. Still, at the same time, she was incapable of implementing this insight practically in the process of assembling an instrument from the spreadsheet tool.

In summary, it is argued that the process of instrumental genesis was present when students worked with the first item. The other two items appeared more difficult for the students due to the involved usage schemes. Although some students conceptually understood the utility of applying a formula and the benefit of using a sum function – the absence of instrumented techniques, along with evidence from the instrumentation processes, indicates a lack of instrumental genesis.

Discussion and conclusions

The presented study aimed to investigate aspects of student-tool-interaction, essential to consider when designing digital tools for assessment. This aim was operationalized by investigating instrumented techniques and data from video and interviews related to utilization schemes and instrumentation when the students worked with the spreadsheet tool items.

The study findings suggest that instrumental genesis is more likely to occur in assessment situations where interactive spreadsheet tools involve intuitive instrumented techniques and usage schemes. However, for items involving more complex instrumented techniques the instrumental genesis process is considered more challenging – even though some students might conceptually understand the benefits of using the functions provided by the spreadsheet tools. This issue might be related to the item design. For the first two items, the initial action – concerning the usage schemes, including techniques for sorting data and selecting numerous cells – is more technical oriented. For the third item, however, it is significant to note that the initial move of producing and implementing a formula seems more conceptually oriented. In contrast, the follow-up operation – copying and filling down the formula – is generally tool-related and technical.

Since some students conceptually understood the benefit of using a formula and a sum function, a plausible explanation is that the absence of instrumental genesis might merely result from the lack of instrumental techniques in related usage schemes. Some students found ways around this problem and used their calculator instead of the spreadsheet tool, to sum up the data. This relates to a possible non-optimal match between task and technique; in this case, it was quite straightforward for the students to sum the limited data using a calculator. A possibility in a future study would be to investigate more intuitive spreadsheet tools, for instance, tools using select and calculation functions from drop-down menus in the spreadsheet tool. Nevertheless, restricting digital tools to basic functions might cause construct underrepresentation (Messick, 1989) whenever the construct deals with higher-order digital skills. On the other hand, items comprising high-fidelity digital contexts might focus on instrumented techniques beyond the range of students' usage schemes, possibly causing construct-irrelevant variance (Messick, 1989). In this tension between construct underrepresentation and construct-irrelevant variance, one challenge is to obtain a suitable balance between the intentions behind assessment and what students can accomplish using digital tools in the process towards instrumental genesis.

Although there are challenges associated with using spreadsheet tools in assessment situations, these tools offer innovative applications, such as interactive functionalities and calculation capabilities (Haspekian, 2014). Introducing digital tools might also shift the assessment focus from routine calculations to broader mathematical competencies (Stacey & Wiliam, 2013; Yerushalmy et al., 2017). However, incorporating spreadsheet tools into assessment situations is far from straightforward. The results of this study indicate that students are struggling with fundamental instrumental techniques. Thus, it is crucial not to take basic tool-related techniques for granted. Failing to do so may require students to learn a digital tool during assessment, potentially undermining assessment validity. Whenever an assessment aims to evaluate conceptual understanding within an instrumented actions scheme, it therefore seems crucial to clarify to teachers and students in advance which instrumented techniques will be required.

While the presented items are just examples of digital technology utilized in assessment, these examples may contribute to future vital findings with implications related to using digital tools in assessments. Analyzing students' work with items that contain components beyond the range of spreadsheet tools can offer further progressions of the presented research. Digital tools to consider include, for instance, dynamic geometry systems, computer algebra systems (CAS), and graph-calculating tools. Other potential research objects concerning spreadsheet items are other agents in education – teachers and test developers, for instance.

The presented study offers valuable insights into instrumented techniques (specifically the absence of instrumented techniques) concerning instrumental genesis when students work with spreadsheet items. However, a limitation of this study is the number of participants ($n = 8$). Nevertheless, the decision has been made to combine observational data with interview data, enabling more profound insights into students' reasoning while applying digital tools – a necessary step in better understanding students' usage of digital tools. Notwithstanding the limited sample, the study adds to the understanding of instrumented techniques about instrumental genesis and provides some aspects to consider when similar interactive tools are used in assessment. The findings are not claimed to be generalizable; instead, the research presented represents a snapshot of what may occur when students with limited technical skills engage with spreadsheet tool items.

References

Artigue, M. (2002). Learning mathematics in a CAS environment: the genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematical Learning*, 7 (3), 245–274. https://doi.org/10.1023/A:1022103903080

Beller, M. (2013). Technologies in large-scale assessments: new directions, challenges, and opportunities. In M. von Davier, E. Gonzalez, I. Kirsch & K. Yamamoto (Eds.), *The role of international large-scale assessments: perspectives from technology, economy, and educational research* (pp. 25–45). Springer. https://doi.org/10.1007/978-94-007-4629-9_3

Bennett, R. E. (2002). Inexorable and inevitable: the continuing story of technology and assessment. *Journal of Technology, Learning, and Assessment*, 1 (1), 1–24. https://doi.org/10.1002/9780470712993.ch11

Borkulo, S. P. van, Chytas, C., Drijvers, P., Barendsen, E. & Tolboom, J. (2023). Spreadsheets in secondary school statistics education: using authentic data for computational thinking. *Digital Experiences in Mathematics Education*, 9, 420–443. https://doi.org/10.1007/s40751-023-00126-5

Brinkmann, S. & Kvale, S. (2018). *Doing interviews*. SAGE. https://doi.org/10.4135/9781529716665

Bryant, W. (2017). Developing a strategy for using technology-enhanced items in large-scale standardized tests. *Practical Assessment, Research, and Evaluation*, 22 (1), 1–10. https://doi.org/10.7275/70yb-dj34

Buteau, C., Gueudet, G., Muller, E., Mgombelo, J. & Sacristán, A. I. (2020). University students turning computer programming into an instrument for "authentic" mathematical work. *International Journal of Mathematical Education in Science and Technology*, 51 (7), 1020–1041. https://doi.org/10.1080/0020739X.2019.1648892

Chong, C.-K., Puteh, M. & Goh, S.-C. (2015). Framework to integrate spreadsheet into the teaching and learning of financial mathematics. *Electronic Journal of Mathematics & Technology*, 9 (1), 92–106.

Dettori, G., Garuti, R. & Lemut, E. (2002). From arithmetic to algebraic thinking by using a spreadsheet. In R. Sutherland, T. Rojano, A. Bell & R. Lins (Eds.), *Perspectives on school algebra* (pp. 191–207). Springer. https://doi.org/10.1007/0-306-47223-6_11

Drijvers, P. (2018). Digital assessment of mathematics: opportunities, issues and criteria. *Mesure et Évaluation En Éducation*, 41 (1), 41–66. https://doi.org/10.7202/1055896ar

Drijvers, P., Godino, J., Font, V. & Trouche, L. (2013). One episode, two lenses. *Educational Studies in Mathematics*, 82 (1), 23–49. https://doi.org/10.1007/s10649-012-9416-8

Drijvers, P. & Gravemeijer, K. (2005). Computer algebra as an instrument: examples of algebraic schemes. In D. Guin, K. Ruthven & L. Trouche (Eds.), *The didactical challenge of symbolic calculators: turning a computational device into a mathematical instrument* (pp. 163–196). Springer. https://doi.org/10.1007/0-387-23435-7_8

Drijvers, P., Kieran, C., Mariotti, M. A., Ainley, J., Andresen, M. et al. (2010). Integrating technology into mathematics education: theoretical perspectives. In C. Hoyles & J.-B. Lagrange (Eds.), *Mathematics education and technology-rethinking the terrain: the 17th ICMI study* (pp. 89–132). Springer. https://doi.org/10.1007/978-1-4419-0146-0_7

Guin, D. & Trouche, L. (2002). Mastering by the teacher of the instrumental genesis in CAS environments: necessity of instrumental orchestrations. *ZDM*, 34 (5), 204–211. https://doi.org/10.1007/BF02655823

Haspekian, M. (2005). An "instrumental approach" to study the integration of a computer tool into mathematics teaching: the case of spreadsheets. *International Journal of Computers for Mathematical Learning*, 10 (2), 109–141. https://doi.org/10.1007/s10758-005-0395-z

Haspekian, M. (2014). Teachers' instrumental geneses when integrating spreadsheet software. In A. Clark-Wilson, O. Robutti & N. Sinclair (Eds.), *The mathematics teacher in the digital era: an international perspective on technology focused professional development* (pp. 241–275). Springer. https://doi.org/10.1007/978-94-007-4638-1_11

Haspekian, M. & Fluckiger, C. (2022). Analyzing teachers' views on the integration of computer science into mathematics teaching. In J. Hodgen, E. Geraniou, G. Bolondi & F. Ferretti (Eds.), *Proceedings of CERME 12*. ERME.

Hoyles, C. & Noss, R. (2003). What can digital technologies take from and bring to research in mathematics education? In A. J. Bishop, M. A. Clements, C. Keitel, J. Kilpatrick & F. K. S. Leung (Eds.), *Second international handbook of mathematics education* (pp. 323–349). Kluwer. https://doi.org/10.1007/978-94-010-0273-8_11

Messick, S. A. (1989). Validity. In R. L. Linn (Ed.), *Educational measurement* (3rd ed., pp. 13–103). American Council on Education/Macmillan.

Mills, C. & Breithaupt, K. (2016). Current issues in computer-based testing. In C. S. Wells, M. Faulkner-Bond & E. Hambleton (Eds.), *Educational measurement: from foundations to future* (pp. 208–220). Guilford.

Misfeldt, M. & Jankvist, U. T. (2018). Instrumental genesis and proof: understanding the use of computer algebra systems in proofs in textbook. In L. Ball, P. Drijvers, S. Ladel, H.-S. Siller, M. Tabach & C. Vale (Eds.), *Uses of technology in primary and secondary mathematics education: tools, topics and trends* (pp. 375–385). Springer. https://doi.org/10.1007/978-3-319-76575-4_22

Ndlovu, M., Wessels, D. & Villiers, M. de. (2011). An instrumental approach to modelling the derivative in Sketchpad. *Pythagoras*, 32 (2), Article 2. https://doi.org/10.4102/pythagoras.v32i2.52

OECD (2018). *PISA 2021 mathematics framework* (second draft). OECD.

Özkale, A. & Özdemir Erdoğan, E. (2021). An instrumental genesis perspective on the students' using spreadsheet for the interest concept and calculations. *Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education*, 15 (2), 282–308. https://doi.org/10.17522/balikesirnef.1022733

Rabardel, P. (1995). *Les hommes & les technologies: approche cognitive des instruments contemporains* [Men and technologies – a cognitive approach to contemporary instruments]. Armand Colin.

Rabardel, P. (2002). *People and technology: a cognitive approach to contemporary instruments*. Université Paris. https://hal.archives-ouvertes.fr/file/index/docid/1020705/filename/people_and_technology.pdf

Sangwin, C. J. (2013). *Computer aided assessment of mathematics*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199660353.001.0001

Stacey, K. & Wiliam, D. (2013). Technology and assessment in mathematics. In M. A. Clements, A. J. Bishop, C. Keitel, J. Kilpatrick & F. K. S. Leung (Eds.), *Third international handbook of mathematics education* (pp. 721–751). Springer. https://doi.org/10.1007/978-1-4614-4684-2_23

Sutherland, R. & Rojano, T. (1993). A spreadsheet approach to solving algebra problems. *Journal of Mathematical Behavior*, 12 (4), 353–383.

Tabach, M., Hershkowitz, R. & Arcavi, A. (2008). Learning beginning algebra with spreadsheets in a computer intensive environment. *The Journal of Mathematical Behavior*, 27 (1), 48–63. https://doi.org/10.1016/j.jmathb.2008.04.002

Thomas, M. O. J. (2009). Hand-held technology in the mathematics classroom: developing pedagogical technology knowledge. In J. Averill, D. Smith & R. Harvey (Eds.), *Teaching secondary school mathematics and statistics: evidence-based practice* (pp. 147–160). NZCER.

Topcu, A. (2011). Effects of using spreadsheets on secondary school students' self-efficacy for algebra. *International Journal of Mathematical Education in Science and Technology*, 42 (5), 605–613. https://doi.org/10.1080/0020739X.2011.562311

Trouche, L. (2000). La parabole du gaucher et de la casserole à bec verseur: étude des processus d'apprentissage dans un environnement de calculatrices symboliques. *Educational Studies in Mathematics*, 41 (3), 239–264. https://doi.org/10.1023/A:1003939314034

Trouche, L. (2004). Managing the complexity of human/machine interactions in computerized learning environments: guiding students' command process through instrumental orchestrations. *International Journal of Computers for Mathematical Learning*, 9 (3), 281–307. https://doi.org/10.1007/s10758-004-3468-5

Trouche, L. (2005). An instrumental approach to mathematics learning in symbolic calculator environments. In D. Guin, K. Ruthven & L. Trouche (Eds.), *The didactical challenge of symbolic calculators* (pp. 137–162). Springer-Verlag. https://doi.org/10.1007/0-387-23435-7_7

Verillon, P. & Rabardel, P. (1995). Cognition and artifacts: a contribution to the study of though in relation to instrumented activity. *European Journal of Psychology of Education*, 10 (1), 77–101.

Vygotskij, L. S. (1978). *Mind in society: the development of higher psychological processes*. Harvard U.P.

Way, D. W., Davis, L. L., Keng, L. & Strain-Seymour, E. (2016). From standardization to personalization: the comparability of scores based on different testing conditions, modes, and devices. In F. Drasgow (Ed.), *Technology and testing: improving educational and psychological measurement* (pp. 260–284). Taylor & Francis. https://doi.org/10.4324/9781315871493-21

Yerushalmy, M., Nagari-Haddif, G. & Olsher, S. (2017). Design of tasks for online assessment that supports understanding of students' conceptions. *ZDM*, 49 (5), 701–716. https://doi.org/10.1007/s11858-017-0871-7

Note

1 Swedish school has a 6-scale grading system. The grades are designated as A–F, with A–E as passing grades, and A being the highest grade.

Mattias Winnberg

Mattias Winnberg is a PhD student at the ASSESS research school (Stockholm University), which focuses on knowledge assessment within educational systems. He also works as a test developer for the national mathematics tests in the PRIM group at the Department of Teaching and Learning. His research in mathematics education addresses key challenges in integrating digital tools into assessments.

mattias.winnberg@su.se

Appendix A

Item 1 Smartphone use

Smartphoneanvändning i olika länder

Du kan sortera data i kalkylbladet genom att trycka på sorteringsknapparna A-D. Data i kalkylbladet kommer då att sorteras i stigande ordning. Använd sorteringsknapparna för att utvärdera påståendet.

A	B	C	D
Land	Befolkning (miljoner)	Antal smartphone-användare (miljoner)	Andel smartphone-användare (%)
Bangladesh	166, 735	8, 92	5
Indonesien	266, 357	67, 57	25
Japan	125, 738	65, 28	52
Malaysia	31, 571	20, 98	38
Pakistan	200, 663	23, 23	12
Filippinerna	105, 341	28, 63	27
Thailand	68, 416	30, 49	45
Turkiet	81, 086	44, 77	55
Vietnam	96, 357	29, 04	30

Landet med den största befolkningen har också det största antalet smartphoneanvändare.

- Sant
- Falskt

Landet med det minsta antalet smartphoneanvändare har också den minsta befolkningen.

- Sant
- Falskt

Landet med den högsta andelen smartphoneanvändare har också den minsta befolkningen.

- Sant
- Falskt

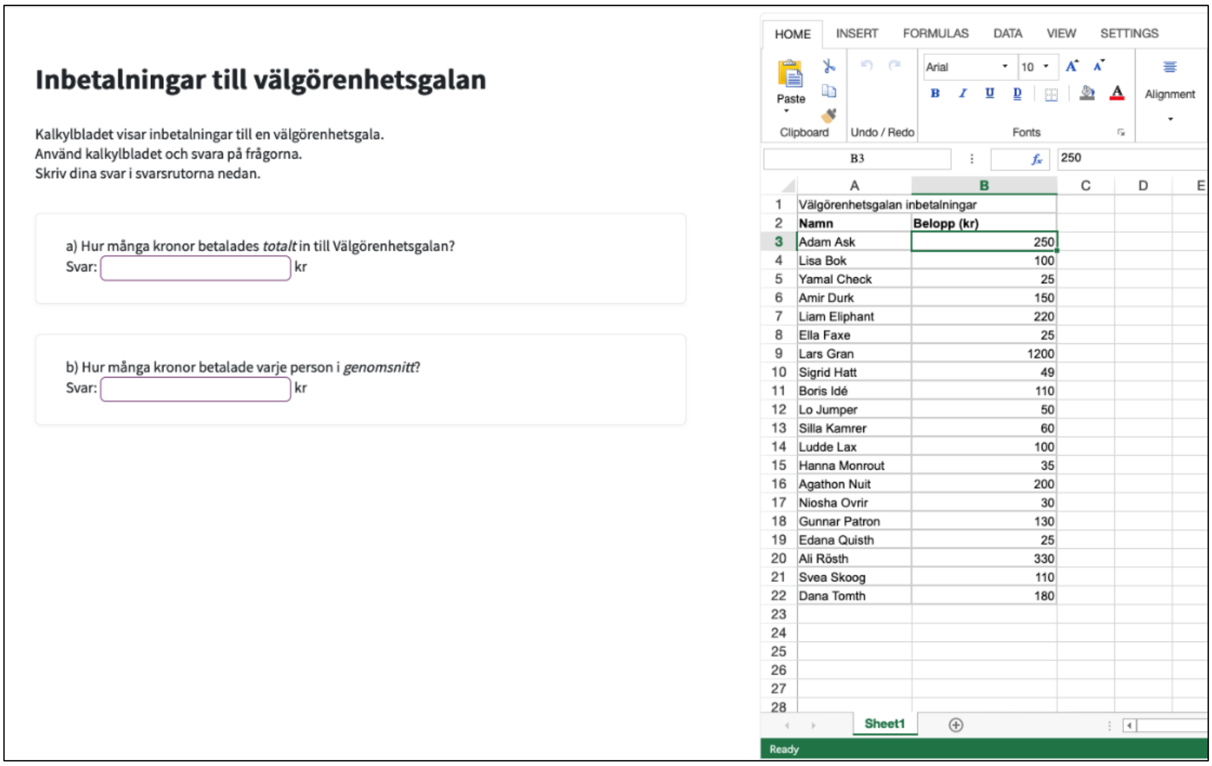
Landet med medianen av andelen smartphoneanvändare är också landet med medianen av antalet smartphoneanvändare.

- Sant
- Falskt

Note. Translation from Swedish:
You can sort the data in the spreadsheet by selecting the sort buttons A–D. The data in the spreadsheet will then be sorted in ascending order. Use the sort buttons to evaluate each statement.
[Land] [Population (millions)] [Number of smartphone users (millions)] [Proportion of smartphone users (%)]
Statements:
The country with the largest population also has the largest number of smartphone users. (True/False)
The country with the fewest number of smartphone users also has the smallest population. (True/False)
The country with the highest proportion of smartphone users also has the smallest population. (True/False)
The country with the median proportion of smartphone users is also the country with the median number of smartphone users. (True/False)

Appendix B

Item 2 Money raised at a charity gala



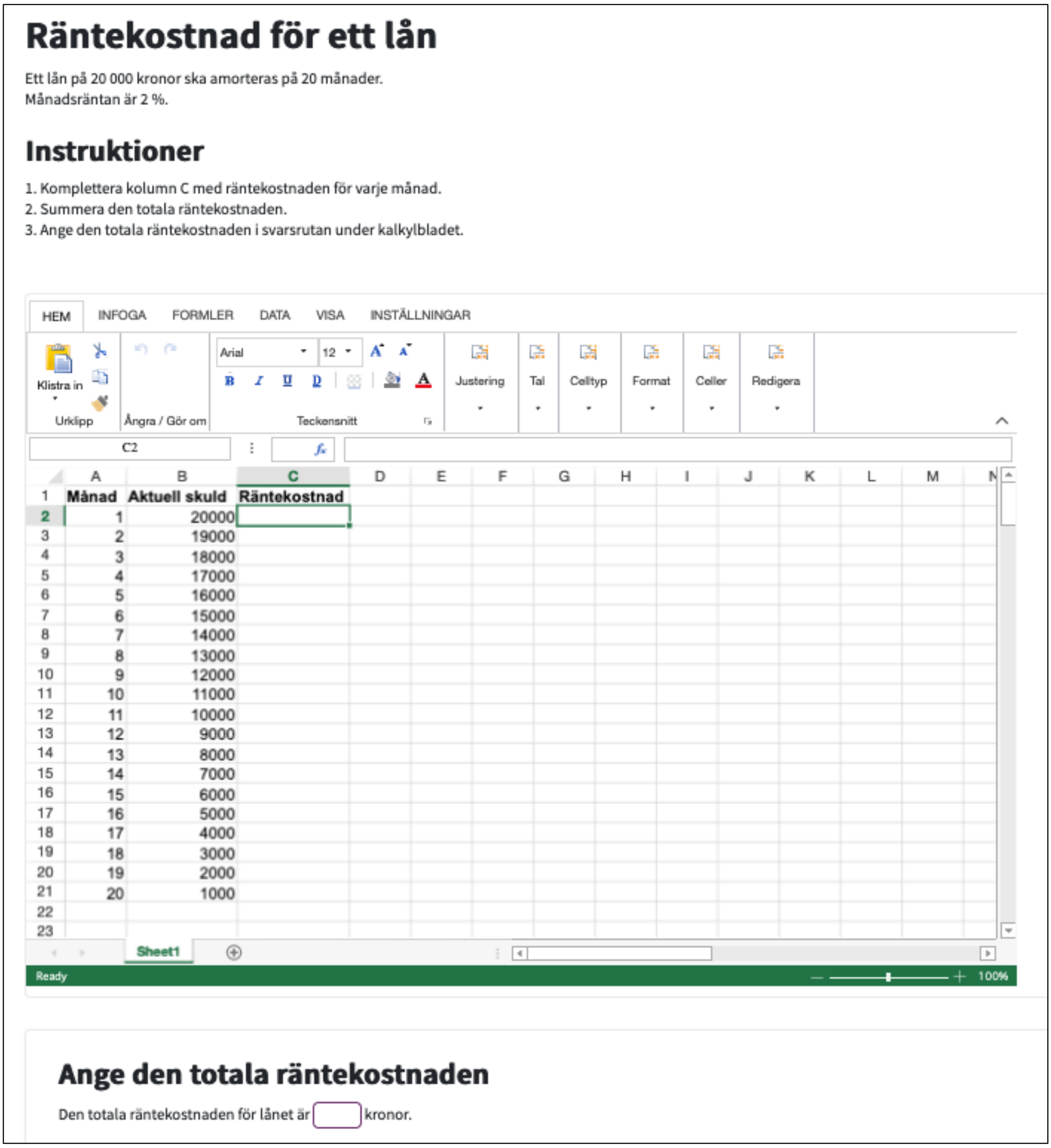
	A	B
1	Välgörenhetsgalan inbetalningar	
2	**Namn**	**Belopp (kr)**
3	Adam Ask	250
4	Lisa Bok	100
5	Yamal Check	25
6	Amir Durk	150
7	Liam Eliphant	220
8	Ella Faxe	25
9	Lars Gran	1200
10	Sigrid Hatt	49
11	Boris Idé	110
12	Lo Jumper	50
13	Silla Kamrer	60
14	Ludde Lax	100
15	Hanna Monrout	35
16	Agathon Nuit	200
17	Niosha Ovrir	30
18	Gunnar Patron	130
19	Edana Quisth	25
20	Ali Rösth	330
21	Svea Skoog	110
22	Dana Tomth	180

Note. Translation from Swedish:
The spreadsheet displays donations at a charity gala. Use the spreadsheet to answer the questions.
Write your answers in the boxes below.

a) How much was raised, *in total*, during the charity gala? Answer: ☐ SEK
b) How much did each person donate, *on average*? Answer: ☐ SEK

Appendix C

Item 3 Interest cost for a loan



Räntekostnad för ett lån

Ett lån på 20 000 kronor ska amorteras på 20 månader.
Månadsräntan är 2 %.

Instruktioner

1. Komplettera kolumn C med räntekostnaden för varje månad.
2. Summera den totala räntekostnaden.
3. Ange den totala räntekostnaden i svarsrutan under kalkylbladet.

	A	B	C
1	Månad	Aktuell skuld	Räntekostnad
2	1	20000	
3	2	19000	
4	3	18000	
5	4	17000	
6	5	16000	
7	6	15000	
8	7	14000	
9	8	13000	
10	9	12000	
11	10	11000	
12	11	10000	
13	12	9000	
14	13	8000	
15	14	7000	
16	15	6000	
17	16	5000	
18	17	4000	
19	18	3000	
20	19	2000	
21	20	1000	
22			
23			

Ange den totala räntekostnaden

Den totala räntekostnaden för lånet är [ ] kronor.

Note. Translation from Swedish:
A loan of 20,000 SEK is to be amortized in 20 months.
The monthly interest rate is 2%.
Instructions
1. Complement column C with the interest cost for each month.
2. Summarize the total interest cost.
3. State the total interest cost in the response box below the spreadsheet.
[Month] [Current debt] [Interest cost]
State the total interest cost.
The total interest cost on the loan is [ ] SEK.