MASTER

# Mathematics teachers' perceptions on the use of the Graphing Calculator and other digital tools

Beckers, Jim; van Niekerk, Ruben W.A.

*Award date:*
2021

Mathematics teachers' perceptions on the use of the Graphing Calculator and other digital tools

Jim Beckers (student 1), 0903288,

Informatica

Ruben van Niekerk (student 2), 0948235,

Wiskunde

Onderzoek van Onderwijs (*10 EC*)

Supervisor - Birgit Pepin

TU/e

# Verklaring inzake TU/e Gedragscode Wetenschapsbeoefening in het kader van de Masterscriptie

Ik heb kennis genomen van de TU/e Gedragscode Wetenschapsbeoefening[1].

Hierbij verklaar ik dat mijn Masterscriptie conform de regels van de TU/e Gedragscode Wetenschapsbeoefening tot stand is gekomen.

Datum

29-06-2021

Roepnaam Achternaam (student 1)

Jim Beckers

Roepnaam Achternaam (student 2)

Ruben van Niekerk

Handtekening (student 1).

Handtekening (student 2).

*Lever de ondertekende verklaring in bij de coördinator van Onderzoek van Onderwijs*

[1] Zie: http://www.tue.nl/universiteit/over-de-universiteit/integriteit/wetenschappelijke-integriteit/
Hier is ook de Nederlandse Gedragscode Wetenschapsbeoefening van de VSNU te vinden.
Meer informatie over wetenschappelijke integriteit is te vinden op de websites van de TU/e en de VSNU.

# Table of Contents

# Summary

During tutoring, we noticed that some students use their (graphing) calculator (GC) for trivial computations. This made us wonder whether GCs are actually perceived to enhance or reduce student learning. We focused on the teachers' perception of the use of GCs and other digital tools. We first wanted to find out what tools teachers used, how they used them and what their thoughts were about the allowance of the GC at the final examinations. The data collection strategies include a questionnaire to the teachers about their views on the GC, to collect statistically relevant data. This was then followed up by an interview, to obtain qualitative data for developing better insights into the reasons for their views. We found that their views regarding the GC differed enormously, while there was consensus about other digital tools. In their view, both have a lot of potential, but students were apparently unable to use them optimally, mainly because of curriculum overload.


***Keywords***— Graphing calculator, Digital tools

# Introduction

The Graphing Calculator (GC) has been the topic of many debates for as long as it has been used in the Dutch secondary education, even in political debates (van Bijsterveldt-Vliegenthart, 2012). When it was first introduced, it was widely adopted by many subjects for the national examinations. However, after some years its use has declined to the point where it is only still in use for two topic areas of the mathematics national examinations (Drijvers, 2020). A lot of research has also been conducted regarding the consequences of using a GC, as many researchers and teachers were interested in the effects it had on student learning and performance (Penglase & Arnold, 1996; Ellington, 2003, 2006). As technology progressed, other digital tools became available for the use in education, such as online Applets (Perkins et al., 2006) or complete online tools like GeoGebra (Hohenwarter, 2002). These digital tools can offer the same functionalities as the GC, and often with better availability or ease of use. Another development in education where laptops have now almost become a commodity in the classrooms (Koopmans, 2018), has led to the point of questioning whether or not the GC still has a place in our modern education. Students now have access to more advanced technology in the form of laptops as well as all the additional digital tools such a medium provides. Hence, the question arises whether students still need to use a GC.

At the moment the Dutch mathematics examination program dictates the use of the GC in the national examinations, and by extension the use of the GC or other digital tools in mathematics lessons. For instance, students are not allowed to use a regular calculator during the mathematics final examinations, only a GC is allowed. This current program was introduced in 2015, after a long development of almost ten years

(Vernieuwingscommissie wiskunde cTWO, 2012). The way the GC should be used in the program was decided based on research performed as early as 2008 (cTWO, 2008). The first real examinations using this new program took place in 2017 and 2018, depending on the level of education. This was ten years after the research on the GC had been published. Moreover, in 2018 an investigation was performed on how future-proof the ICT practices are in the current examinations (CvTE-commissie, 2018). In that report it was concluded that researchers would like to see more modern technology than the currently used GC, such as GeoGebra. This meant that just after the new program was in use, they GC was already considered outdated. A new examination program is currently being developed. The development started almost as soon as the previous program had been accepted in 2013, and by now in 2021 the first draft of the new educational goals of the program is being formed (Slob, 2020; Curriculum.nu, n.d.-b, n.d.-a).

This is where the aim of this study comes into view. While the effects of the GC or other digital tools have been extensively investigated, teachers' perceptions on their use has received little attention. As the new program is currently being developed, it is the right moment to investigate this. Teachers will in the end be responsible for implementing the chosen digital tool into their teaching, and from research we know that this implementation will decide whether the tool will foster or hinder learning (Drijvers, 2020). Even though the GC has been proven to aid students in learning mathematics, it has been removed from the examination program in favor of pen-and-paper skills.(Ellington, 2003) The reason for this was that students were relying too much on GC results, rather than on mathematical insight. It is therefore important to know what teachers' perceptions are on the use of the GC and other digital tools in mathematics education. With the results of this study we aim to provide recommendations for the use of digital tools in mathematics for the new program, based on the perception of teachers, as the formation of the new program has only just started and pilots are not planned until 2023 (Curriculum.nu, n.d.-a).

# Theoretical framework

The relevant theory for this study can be divided into four separate topics: (1) Digital tools and their effect in mathematics education; (2) mathematics learning, in particular mathematical proficiency and deep learning; (3) functions and graphs, as it is one of the two topics in which the GC is still being used; (4) and teachers' perceptions on the use of GCs in mathematics education.

## Digital tools

Amongst digital tools, calculators and GCs are the most commonly used (Waits & Demana, 2000). As mentioned earlier in the Introduction, the topic of calculators and GCs has been studied extensively. Two meta-analyses, performed on 54 (Ellington, 2003) and 42 (Ellington, 2006) studies, provide a clear overview of the results of such studies. The first meta-analysis focused on the effects of using calculators on students' acquisition of operational and problems-solving skills, as well as attitudes towards mathematics. In all three areas the use of calculators showed improvements, leading to the support of calculator use in mathematics. The second meta-analysis focused on achievements and attitude levels of students. It showed that students benefitted from the use of calculators in their study of mathematics, and even showed that there were no circumstances, within the studies of their meta-analysis, under which students taught without calculators outperformed students taught with access to calculators.

In addition to the GC, an example of a digital tool has been investigated by Drijvers (2020). In this study the dialectic, meaning controversial or contradictory, relationship between the use of digital tools and the higher-order goals of Dutch mathematics education was addressed. The focus was on the GC and online Realistic Mathematics Education (RME). The results of the study show that the use of digital tools, in addition to paper and pen, may lead to new opportunities. Moreover, the author claimed that this results in a subtle interaction between the technical mastery of digital tools and the conceptual understanding of mathematics, where a mismatch may hinder learning and a natural fit may foster mathematical understanding. This illustrates the difficulty for teachers to implement digital tools effectively in their lessons. It also shows why teachers might disapprove of the use of digital tools, since using a digital tool can also negatively affect student learning depending, on the implementation. Drijvers provides a clear depiction of the development of the use of the GC in Dutch mathematics education. Showing that it was widely adopted into the national examinations, even for other courses than mathematics, but that over the years the use declined due to students depending too much on GC skills instead of mathematical insight. In the end, the use of the GC did not have the effect that was hoped for, he claimed.

A study that focused on the results of using digital tools, has been conducted by Hillmayr, Ziernwald, Reinhold, Hofer, and Reiss (2020). They again performed a meta-analysis on the potential of digital tools to enhance mathematics learning, by examining 92 studies published since the year 2000. They examined how the use of such digital tools influenced student learning outcomes and attitudes. The overall effects show a medium, significantly positive affect on learning outcomes, and a small, significantly positive effect on attitudes. The learning outcomes in this study were specified as student performances. Simulations, such as dynamic mathematical tools, and intelligent tutoring systems were the types of digital tools which provided the largest effects. They also noted the importance of teacher education in the use of the digital tools, as well as that complementary use of digital tools was more beneficial than replacing existing methods. Both of these findings were also noted in the meta-analyses on calculators and GCs.

## Mathematics learning

Within mathematics learning, we lean on the notions of mathematical proficiency and deep learning as the most relevant for this study. Mathematical proficiency is based on five components or strands: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning and productive disposition (National Research Council, 2001). Mathematics teachers are expected to provide opportunities for students to develop these five strands, if they are to develop mathematical proficiency. Concerning *conceptual understanding*, a student knows more than isolated facts and methods. They understand why a mathematical idea is important and the kinds of contexts in which it is useful. Regarding *procedural fluency*, a student knows procedures and when to use them, and he can perform them flexibly, accurately, and efficiently. A student developing *strategic competence*, can formulate mathematical problems, represent them, and solve them. Using *adaptive reasoning*, a student can think logically about relationships among concepts and situations, consider alternatives, reason correctly, and justify conclusions. Students with a *productive disposition*, see that mathematics makes sense and is both useful and worthwhile, they believe that steady effort pays off, and see themselves as effective learners and doers of mathematics. It is important to note that the five strands are interwoven and interdependent in the development of mathematical proficiency (National Research Council, 2001).

Mathematics learning has also been linked to understanding, by Hiebert and Carpenter (1992). They investigated learning and teaching with understanding for mathematics by presenting a framework for examining issues with understanding. For learning with understanding they stated that: "The growth of mathematical knowledge can be viewed as a process of constructing internal representations of information and, in turn, connecting the representations to form organized networks" (p.80). This is in correspondence the definition of conceptual understanding from the abovementioned five strands. Their statement is also part of a common definition of deep learning, e.g. joining concepts (Lyke & Young, 2006).

A relevant study which focused on teachers' perspectives was performed by Rillero (2016). This study deployed an adaptive questionnaire to gain understandings of teachers' perspectives regarding deep conceptual learning (DCL) in mathematics. The results of the questionnaire showed that 87% of the 425 teachers were using DCL methods and 78% used technology to support DCL. Unfortunately, no specifics of the types of technology were given in the study. However, we can conclude that digital tools are likely to be used by teachers to support deep learning. Another important finding was that only 55% of the teachers' current instructional material actually supported DCL, suggesting that there is still room for improvement. The researches do note that it was an exploratory study that used a sample of convenience, so it was not possible to generalize the results of this study. Neither does the study provide insights into teachers' perspectives in the Netherlands, since it was conducted in the United States.

## Functions and graphs

Before the introduction of GCs or other tools, it took students a lot of effort to calculate and draw the graph of a function by hand. This has changed significantly when digital tools were introduced in the classrooms. More than 30 years ago, Leinhardt, Zaslavsky, and Stein (1990) stated that "more than perhaps any other early mathematics topic, technology dramatically affects the teaching and learning of functions and graphs" (p.7). Although it has generally been recognized that understanding graphs is one of the most useful skills for students to develop in mathematics classes, there were many students finding it hard to understand. The interpretation of graphs usually caused more problems than being able to draw the graph (Hennessy, 1999).

With the introduction of GCs, students were able to easily plot and visualize graphs, even without prior knowledge about graphs. This way students could plot and compare many graphs and their corresponding equations to examine the relationship between graphical entailments and algebraic parameters (Leinhardt et al., 1990). The visualization tool also had other useful features. For example, 'zooming in' could give a clear view of the gradient of a function. This is 'cognitively more direct' and can therefore be used by students to get a better understanding of concepts like 'gradient' (Sue & David, 2005).

## Teachers' perceptions

Even though there has been research on the effects of the GC, there is limited research on the teachers' perceptions and beliefs concerning the GC. Molenje (2012) surveyed 81 secondary mathematics teachers to investigate their professed beliefs about

GCs. More specifically: "The survey was designed to elicit the teachers' beliefs about various aspects related to the use of graphing calculators in the teaching of and learning about linear and quadratic functions, as well as give the teachers an opportunity to report on how often they used graphing calculators in their classrooms." (p.143). This is similar to the aims of this study, but does not provide an accurate representation for the current situation in the Netherlands, as it was conducted almost ten years ago in the United States. The most noteworthy result of the study was that the teachers in this study seemed to believe in the potential of the GC to enhance student learning. Another interesting finding from this study was that the teachers involved agreed that students should be free to explore with the GC. The amount of student exploration was highly influenced by the frequency in which teachers used a GC in their lessons, with a high frequency corresponding to more student exploration.

A second study focussing on teachers' perspectives was performed by Karadeniz (2015), who investigated teachers' perspectives on student learning and their own teaching when using GCs. The results of the study showed that teachers reported that GCs positively affected student learning. However, they also reported that students' arithmetic skills were negatively affected when using a GC. Additionally, five of the eleven involved teachers indicated that their students relied on the GC too much. Unfortunately, the data used in this study were collected in the 2007-2008 school year in the United States, which again does not provide an accurate current overview of teachers' perceptions in the Netherlands. Both Molenje and Karadeniz also provided examples of interviews and questionnaires useful for this study.

### Summary

To conclude, there is little previous research regarding teachers' perceptions on the use of digital tools on the topic of functions of graphs. The studies that have been performed are older and do not portray the situation in the Netherlands. We do know that digital tools, and more specifically the GC, can have a positive effect on student learning. However, it does not mean that this is also reflected in the curriculum, as illustrated by Drijvers (2020). We have also seen that the use of digital tools has transformed the way functions and graphs are taught and learned, and what we mean by mathematics learning regarding mathematical proficiency and deep learning. Combining the results of these four topics leads us to the research questions for this study.

## Research questions

The main research question of this paper is the following:
*What are teachers' perceptions on the use of the graphing calculator and other digital tools for the enhancement of student learning in Dutch (upper) secondary mathematics education?*

We want to answer this question by considering the following sub-questions:

1. *Which digital tools, including the graphing calculator, are used by teachers?*
2. *How are digital tools, in particular the graphing calculator, used by teachers?*
3. *What are teachers' views on the Dutch policy regarding digital tools, like the graphing calculator?*

4. *According to teachers, in which ways can digital tools, in particular the graphing calculator, be used to enhance student learning?*

5. *How did the COVID-19 pandemic influence the teachers' perceptions on the use of the graphing calculator and other digital tools?*

The first four sub-questions are necessary to get an overview for the answer of the main research question. In order to investigate the perceptions of teachers on the use of the GC and other tools, it is important to make an inventory of the tools that are used. This is done by answering the first sub-question. The second sub-question is necessary to find out in which ways teachers use the tools (e.g. for enhancing student learning). Their views on the use of the tools is definitely dependent on their experiences of using the tools. The third research question explores the Dutch mathematics education policy in terms of the tools provided and allowed for the final examinations. The students are allowed to use a graphing calculator for the final examination, so they need to practice with it. Teachers' perceptions on the graphing calculator can definitely be influenced by the current policy, because they are forced to use it due to examination regulations. At the same time, their views on tools that are not allowed during the final examinations can also depend on that policy. Therefore, it is important to find out their opinions on the Dutch policy regarding the use of the graphing calculator and digital tools. The fourth sub-question focuses on the potential of the graphing calculator and other digital tools, according to teachers' views. It builds further upon the second sub-question. The perceptions of the teachers can be influenced by the potential, affordances and constraints of the tools. The last sub-question is related to the COVID-19 pandemic that lead to online or hybrid education, during this research. Although its answer does not contribute to the main research question, it is still very relevant. The first four sub-questions combined give an overview of the teachers' perceptions regarding the graphing calculator and other digital tools and are therefore sufficient to answer the main research question.

# Methods

In this section, the general methodology will be described, in addition to the target audience, and the two data collection strategies, including validity and data-analysis, that were used in this research.

## General methodology

This study is an exploratory study on mathematics teachers' perceptions on the use of digital tools. To best answer the research questions, we needed both quantitative and qualitative data. To this end, we decided upon first conducting a questionnaire, followed by interviews with some of the respondents. The main goal of the questionnaire was to obtain data to answer the first two research questions. The secondary goal was to find teachers that were willing to be interviewed for additional questions. The main goal of the interviews was to obtain an answer to the third and fourth research questions. Generally, questionnaires provide a high degree of reliability and generalisability, whereas interviews provide a high degree of validity. By using a questionnaire as well as interviews, we have likely countered threats to validity, reliability and generalizability. First, we discuss the questionnaire and subsequently the follow-up interviews.

## Questionnaire

### Sampling

The target audience for the questionnaire were all teachers in the Netherlands who taught mathematics in the upper classes of secondary education. Since the graphing calculator was a mandatory part of the final examinations, all of these teachers would most likely use it in their classes. Therefore, they were suited for our investigation. No specific group within these teachers was selected for this research, but some demographic information about these teachers was obtained with the questionnaire. Not all teachers might also use other digital tools, but this is no issue as we were also interested in reasons not to use other digital tools.

### Data collection strategy

To reach as many teachers as possible, we made use of WiskundE-brief (n.d.) for distributing our questionnaire. This is a newsletter for mathematics teachers in secondary education, published bi-weekly with 4800 recipients. We made a post in their newsletter asking the teachers if they were interested in filling out our questionnaire, which was sent to all 4800 members. The questionnaire itself was made using Microsoft Forms. After distribution, the questionnaire was left open for three weeks, after which it was closed to start with the analysis.

### Content of the questionnaire

The questionnaire was designed by ourselves, with inspiration from other research for the structure and type of questions. For this we used a study by Kock and Pepin

(2019) about secondary school mathematics teachers' selection and use of tools, as they also employed a questionnaire distributed through WiksundE-brief, as well as the study discussed earlier by Molenje (2012) about teachers' perceptions, perspectives and professed beliefs. The questionnaire had four parts. The first part (I) elicited demographic information of the respondent, the second part (II) was about teachers' use of the graphing calculator, part three (III) about other digital tools, and the final part (IV) was about the influence of COVID-19 on their use of digital tools. At the end, there was also an open question where respondents could fill in any comments or remarks regarding the questionnaire, or about the use of digital tools in mathematics. The full questionnaire is listed in Appendix A: Questionnaire items.

The demographic information in Part I was about the age, teaching experience, teaching qualification, specific classes taught and the textbook used by the teacher. This information was used to specify which group of teachers participated in the questionnaire.

Part II about the graphing calculator asked the teachers whether they used a graphing calculator or not, and if so, which one. The types of graphing calculators were based on the allowed graphing calculators of the mathematics final examinations (Hendrikse, 2020). This should provide data with regard to which graphing calculators were used by teachers. Furthermore, they were asked when they used the graphing calculator, and if so, whether this use was teacher or student directed. The teachers were also asked as to what type of tool the graphing calculator was used as, based upon a study by Doerr and Zangor (2000). In all three cases, five-point likert-scales were used for frequency with the options "Never - Rarely - Sometimes - Often - Always". These were placed in ascending order, in order to reduce response-order effects (Chyung, Kennedy, &

Campbell, 2018). This was done for all likert-scale questions in the questionnaire. These three questions should provide answers regarding how teachers use the graphing calculator. The last question in part II asked the respondents about their thoughts and opinions regarding the graphing calculator. Again, with a five-point likert-scale, but now regarding their opinions in ascending order “Strongly disagree - Disagree - Neutral - Agree - Strongly Agree”.

Part III of the questionnaire about the other digital tools was a copy of the second part, to be able to directly compare the other digital tools with the graphing calculator. Only now, instead of asking if they used a graphing calculator and which one, we asked if they used any other digital tools and to specify which ones. This provided the required information about what other digital tools were being used by teachers and how. If teachers did not use either a graphing calculator or other digital tools, the corresponding part of the questionnaire was skipped.

In the final part, Part IV, of the questionnaire, we focused on the change of use of either the graphing calculator or other digital tools during the COVID-19 pandemic. Since during this period teachers in the secondary education had to switch to online lessons. As teachers were forced to give their lessons online via computers or laptops, they might have changed their habits and used of digital tools in their education. A five-point likert-scale was used, regarding the change in frequency of use “Much less - Less - Same - More - Much more”. These questions could provide us with some insight into the effect of the COVID-19 pandemic on the use of digital tools.

## Data-analysis

As pre-processing, all data of the results of the questionnaire were converted into categorical or ordinal data for easier analysis. For all non-likert based questions, the options were numbered starting from 1. For the yes-no questions, a 'No' was labelled as 0 and a 'Yes' as 1. The likert-scale questions were converted to numerical scales, with a 1 for the left-most options (e.g. never, strongly disagree, much less) and a 5 for the right-most options (e.g. always, strongly agree, much more). The only exception to this were questions 13c and 20c, where the order was reversed as the questions are negatively stated. The quantitative data of the questionnaire were analysed in three ways: (1) Descriptive statistics were used to obtain medians, frequencies and percentages to provide the general results of the questionnaire. (2) Reliability checks were performed on different parts of the likert-scale questions. They were grouped per question as follows: 10-12, 13, 17-19, 20 and 21-22. On each group a Cronbach Alpha reliability check was performed. (3) Non-parametric tests were performed to check if there was a significant difference in response between certain groups in our respondents. These groups were based on the demographic information. The Kruskal-Wallis H Test was used in this study with additional Post Hoc testing to see between which groups specifically there was a significant difference. All analysis was performed using statistical analysis software, specifically SPSS. The qualitative data, question 24, was analysed to aid in selecting respondents for the follow-up interviews as well as to see if interesting additional insights were provided by respondents.

## Validity

In total we had 87 responses to the questionnaire. Some respondents notified us about a mistake in the questionnaire. We had made an error in the order of the likert scale of question 20. Throughout the questionnaire we always started with 'fully disagree', however we accidentally reversed the order and started with 'fully agree'. We will go further into detail about this when discussing the results of question number 20. Nevertheless, we ran a reliability check on groups of the likert-scale items. The results of these test are listed in Table 1. We can see that all items are above the 0.7 threshold and we can thus assume that the results of the questionnaire are reliable. For readability, all results of the questionnaire have been put into Appendix B: Results of questionnaire. The most important parts are also listed Section .

Table 1: Reliability test of likert-scale questions

| **Questions** | **Items** | **Responses** | **Cronbach's alpha** |
|---|---|---|---|
| 10-12 | 12 | 86 | 0.726 |
| 13 | 8 | 86 | 0.855 |
| 17-19 | 12 | 69 | 0.848 |
| 20 | 8 | 69 | 0.806 |
| 21-22 | 8 | 87 | 0.853 |

## Interview

### Sampling

The target audience of the interviews was the same group of teachers who participated in the questionnaire. At the end, respondents could fill in, if they were interested in a follow-up interview. From these respondents we selected a group of teachers based upon their answers to the questionnaire. We selected (1) a group of teachers who did not use any other digital tools than the graphing calculator, and (2) a group of teachers who did use other digital tools. Within each of these two groups, we made a distinction between teachers who were positive about the graphing calculator and who were negative about it. We selected two teachers for each of the four groups for the follow-up interview, giving eight in total.

## Data collection strategy

All selected teachers were contacted for the follow up interviews. The interviews were held online with Microsoft Teams, due to the COVID-19 measures in place by the Dutch government. All interviews were recorded using Teams.

## Content of the interviews

The interview was setup as a semi-structured interview, it is included in Appendix C: Interview questions. The interview was divided into four parts. The first part was about the graphing calculator. We first asked the interviewee to give a typical example of the use of the graphing calculator. Next, we asked how the interviewee thought that a graphing calculator could contribute to the learning of mathematics, followed by a question about their thoughts on existing research indicating the positive effect of the graphing calculator based upon the research discussed in the Theoretical framework. This would provide data as to why teachers used a graphing calculator.

The second part was a copy of the first part, only now about the other digital tools used by the interviewee. The same three questions were used. If the interviewee did not use any other digital tools than the graphing calculator, we asked them for their reasons as to not use any other digital tool in their lessons. This would provide data regarding why teachers did or did not use other digital tools.

The third part of the interview discussed the curriculum in place for mathematics in secondary education and the new curriculum being currently developed. We asked the interviewee what their thoughts are on the current state in which the graphing calculator is allowed and other digital tools are not. We also asked if they were informed of the developments currently taking place, and if they would change anything about the curriculum if possible. With this, we would obtain information about the views of teachers of the Dutch policy regarding digital tools.

The final part of the interview was about the future of digital tools in Dutch mathematics education. Here we asked the interviewee what their views are regarding the future of the graphing calculator and other digital tools, how they expect it will be in the future, and how they would like to see it. These data could also help with the views of teachers on the policies.

## Data-analysis

The recorded interviews were processed using speech-to-text software included in Microsoft Word. With these raw transcripts and the original recordings, a full transcript was made for each interview. These transcripts were coded, to allow for synthesis and analysis of the interviews.

For the processing of the data, we originally had planned 21 coding categories, which were obtained by reasoning about common answers to the interview questions for all five categories. These are included in appendix C. During the coding process, we adjusted, combined, added and removed categories and ended up with 19 categories. The categories, their meaning, the number of interviewees who discussed these and their frequencies can be found in Table 2. The codes are Dutch (abbreviations), since the interviews were conducted in Dutch.

The horizontal lines divide the codes in categories with a common theme. The first group of codes, consisting of five codes, is related to the usage of the GC. The second and third group of codes refer to the usage of the GeoGebra and other digital tools respectively. The forth group of codes refers to the curriculum. The fifth group concerns the used methods. Most teachers use 'Getal & Ruimte'. Positive remarks about other methods were not made during the interviews. Finally, there is a category for other comments made during the interviews.

The sample size of five interviews cannot give statistical relevant data, but the views of the interviewees gave interesting insights in the diverse views of Dutch teachers concerning the use of digital tools. In the next section we provide a summary of the interviews and an interpretation.

# Results

In this section we will discuss the results of our study. We will first provide results of the questionnaire, followed by the interviews.

Table 2: Final interviewing codes and categories

| **Code** | **Meaning** | **Number of interviewees** | **Total frequency** |
|---|---|---|---|
| GR Klas | The usage of the GC for classroom instruction | 3 | 5 |
| GR Plot | The usage of the GC for plotting and visualizing functions | 5 | 8 |
| GR Begrip | The usage of the GC to help students understand mathematics | 4 | 5 |
| GR + | Positive aspects of the GC | 2 | 5 |
| GR - | Negative aspects of the GC | 4 | 5 |
| GGB Klas | The usage of GeoGebra for classroom instruction | 1 | 1 |
| GGB Plot | The usage of GeoGebra for visualizing functions | 4 | 5 |
| HM Klas | The usage of other digital tools for classroom instruction | 1 | 1 |
| HM Plot | The usage of other digital tools for visualizing functions | 1 | 1 |
| Overladenheid | The mathematics program being overloaded | 3 | 6 |
| Meetkunde | 2D geometry, removed from the curriculum in 2015 | 2 | 2 |
| Wijziging | The planned changes for the curriculum | 1 | 1 |
| Tk GR | The future of the GC 5 | 6 | |
| TK GGB | The future of GeoGebra | 3 | 3 |
| TK HM | The future of other digital tools | 1 | 1 |
| G en R + | Positive aspects of 'Getal & Ruimte' | 1 | 1 |
| G en R - | Negative aspects of 'Getal & Ruimte' | 3 | 4 |
| LM - | Negative aspects of other methods | 2 | 2 |
| Kosten | Costs associated with the purchase of the GC | 3 | 2 |

## Questionnaire

The results of Part I of the questionnaire, about background information of the respondents, is listed in Tables 3 through 7. Note that for question 5, Table 6, respondents were able to select multiple answers. From the results we see that the age and experience of our respondents lie mainly in the second half of the options, meaning that our respondent were mostly older and also more experienced teachers. Furthermore, almost all (86) teachers were in possession of a teaching qualification and most (73) of a master degree. The different type of classes in Dutch mathematics education were all well represented, with the smallest being taught by only 17 respondents. Finally, the most used textbook was 'Getal & Ruimte' with almost 75% of the respondents using this textbook.

From the results of Part II of the questionnaire about the use of the graphing calculator, we know that all of our respondents have taught the topic of functions and graphs in the past three years. Only one of the respondents did not use a graphing calculator in his/her lessons. Unfortunately, we do not know why, as the respondent did not provide any further information about this at the end of the questionnaire. As to what type of graphing calculator was used, the results are listed in Table 10. The majority used Texas Instruments (49), the rest mostly used Casio (33) and a few used the HP Prime (4). The results of the likert-scale questions, items 10 through 12, are listed in Tables 11 through 13 and Figures 1 through 3. Considering the tables and figures, we can conclude that there is a consensus in the responses, since there are no high standard deviations or multiple peaks visible in the graphs. The Kruskal-Wallis H test, however, showed that there was a significant difference for questions 10.c ($H(3) = 10.287$,

$p = 0.016$) and 10.d ($H(3) = 9.251$, $p = 0.026$) compared to the teaching experience of the respondents, question 3. With Post Hoc testing we identified the two groups for which there was a significant difference to be the '0-5 years' and the '10-20 years' groups. Looking at the results of both groups, we see that the less experience group tended to let students use the graphing calculator less for making exercises and tests compared to the more experienced group.

When we look at when the graphing calculator is used, we see from Table 11 that it was mostly used by students when making exercises and tests. It was also used by teachers when explaining new material or discussing exercises, but this was less frequent than the students using it. About whether the graphing calculator was used in a teacher or student directed way, we know from Table 12 that our respondents were more teacher directed and preferred to explain rather than let students discover themselves. Table 13 shows that the graphing calculator was mostly used to calculate numerical expressions and to visualize functions or data. It was rarely used to collect or analyze data, and it was sometimes used to check ideas or answers.

The results of question 13 are given in Table 14 and Figure 4. Again the Table and Figure show a consensus in the respondents. The Kruskal-Wallis H test showed that there was a significant difference for question 13.e ($H(3) = 9.549$, $p = 0.023$) compared to the age of the respondents, question 2. The Post Hoc testing gave the two groups for which there was a significant difference, namely between the '31-40 years' and '>55 years' groups. The older group was more positive about the influence of the graphing calculator on the mathematics education compared to the middle-aged group. Furthermore, there was also a significant difference for question 13.d ($H(1) = 4.322$, $p = 0.038$) compared to whether or not the respondent also used other digital tools, question 14. The group which used other digital tools was more confident in their abilities using the graphing calculator than the group who did not use other digital tools.

What we additionally learnt about our respondents is that they were mostly indifferent about the positive effect of the graphing calculator on the enhancement of student learning. They did however note that the graphing calculator was a useful tool for visualizing functions or data, and that they were proficient in the use of it. Most noteworthy was that they stated that the graphing calculator should not get a larger role in mathematics education and that it had caused a reduction in math skills of students, although just slightly.

We now consider the results of Part III of the questionnaire about the other digital tools. Of our respondents, almost 80% (69 out of 87) also used other digital tools than the graphing calculator. Which other tools they used and which of those they used the most, is listed in Tables 16 and 17. Again, for question 15 respondents could select multiple answers. From this we know that GeoGebra is the most used digital tool amongst our respondents, with more than 80% (56 out of 69) using it. The results of questions 17 through 19 is given in Tables 18 through 20 and Figures 5 through 7. From the results we see that responses are more spread out compared to similar questions on the graphing calculator, questions 10 through 12. To see if there is a significant difference in the response between different groups of respondents, we again performed the Kruskal-Wallis H test. This showed that there was a significant difference for questions 17.a ($H(3) = 14.481$, $p = 0.002$) and 17.b ($H(3) = 24.097$, $p = 0.000$) compared to the other tool used, question 16. The two groups for which this holds true were the users of

GeoGebra and the users of Desmos, as was obtained by Post Hoc testing. In both cases the user of Desmos were more frequent in their use of the digital tools, than the users of GeoGebra when explaining new material or discussing exercises.

Compared to the GC we see the following difference for the other digital tools. As said before, the other digital tools were never used by students when making tests and they also rarely used it when making exercises. It was reserved mostly for the teacher when explaining new material and sometimes when discussing exercises. This can be found in Table 18. We did not get any decisive information whether the tools are used in a teacher directed or student directed fashion, this is clearest from Figure 6. We can however use some data from the question 19 to help in answering this. In Table 20 we can see that students almost never used the tool for visualizing data, although a digital tool like GeoGebra was almost exclusively used for visualization. From this we can conclude that the tools were mostly used by teachers and not as much by students. This is the general conclusion when comparing tools with the GC. The GC was mostly used by students when making exercises and tests, and the other digital tools were used by teachers when explaining new material. They were used with a different purpose in mind.

The results of question 20 are given in Table 21 and Figure 8. As said earlier, we made a mistake here and reversed the order of the likert-scale. We know by looking at individual responses that some respondents did not see our error and answered opposite to what their opinions were. We had one respondent who used his/her own, self-designed applets, but was really negative about it. It would be more logical if that person was positive, as otherwise he/she would not use such a digital tool. We cannot say for which respondents this error has occurred, therefore we cannot alter these responses to match their opinions. As a result, the results of this question are not as reliable as the rest of the questionnaire. Nevertheless, we see that the respondents were in general more positive about the other digital tools than the graphing calculator, by comparing the responses of this question to those of question 15. To see if there were any significant differences between groups, we ran the Kruskal-Wallis H test again. There was a significant difference for questions 20.c ($H(3) = 12.290$, $p = 0.006$) compared to age, question 2, and 20.h ($H(3) = 8.762$, $p = 0.033$) compared to experience, question 3. With Post Hoc testing we know that the group aged '41-55 years' found the other digital tools to have less of a negative effect on the math skills of students compared to group aged '>55 years', and that the group '>20 years' of teaching experience found that the other digital tools helped more in the development of problem solving skills compared to the group '5-10 years' of teaching experience.

Finally, we have the results of Part IV of the questionnaire about the influence of COVID-19 on their use of digital tools. The results of questions 21 and 22 are listed in Tables 22 and 23, and Figures 9 and 10. From the data we see that there has not been an influence on the use of digital tools due to COVID-19. Moreover, from the Kruskal-Wallis H test there was no significant difference between any groups of our respondents.

## Interviews

We had planned to conduct eight interviews with respondents to the questionnaire. Due to time constraints and a lack of response, we finally conducted five interviews. The interviewees were selected for their different views regarding graphing calculator and other tools. Here, we provide a summary of the interviews.

For clarity, we call the interviewees A to F. Most teachers were unhappy about the current way the graphing calculator is allowed on the final written exam. Teacher D mentioned that the final exam is restricted in the questions that can be asked, since for at most 30 minutes of the 3-hour exam the graphing calculator is needed. The other 150 minutes, no questions can be asked for which the GC would make the question too easy. Contrarily, teacher B viewed the GC as an enabler of different and more understanding-based questions. B said that the GC 'rescues the student from drowning in their calculations' and provides more time for deeper and more interesting questions. Teacher A was in favor for the use of laptops for the final examination, while most other teachers thought that this would be too difficult to set up, both with respect to licensing and some restricted exam mode. Teacher D even suggested allowing laptops during school exams, so the central exam could be done by only a standard calculator. Most teachers agreed that the current calculators are both obsolete and too expensive to purchase. Some suggested to remove some unused features in order to reduce its capabilities and its costs. Another teacher complaint related to the view that GeoGebra was a wonderful tool for two-dimensional geometry, while the CvTE (The organization that makes the curriculum) deleted this subject from the curriculum for the Wiskunde-B examination. This is the more abstract type of mathematics that includes functions and graphs.

So, although the teachers would like to see the current version of the GC be replaced or even removed, most of them still embraced the functionalities for the students to use on the final exam. Teachers who used the GC intensively, used it in classroom instructions mostly for plotting functions. Teachers A and D emphasized the importance of function analysis and deep understanding of functions, while teacher B thought that this was possible because of the GC. Teacher E said to prefer GeoGebra for showing functions, because it was visually more attractive. Teacher B used the graphing calculator for many aspects, including probability theory, statistics and recursion, as a part of wiskunde A, the less abstract form of mathematics education, and functions and graphs as a part of wiskunde B, the more abstract type. He said that the GC enabled deeper understanding of mathematics and was disappointed by his colleagues who thought that pure mathematics problems should be solved with pencil and paper only. These teachers focused in their interview on a lot of negative aspects, such as the costs and the obsolescence of the GC and the fear that mathematics focuses too much on handling a specific machine, instead of the mathematics itself. In conclusion, mainly the ease of visualizing the functions appeared to contribute to student learning, and a significant number of teachers used the GC barely in their classes.

# Discussion and conclusion

We will first address the different sub-questions using the results from the questionnaire and the interviews. Then we will combine the results to answer the main research question. Finally, we will discuss the limitations, possible improvements and further research.

*1. What digital tools, including the graphing calculator, are used by teachers?* — Based upon the results of the questionnaire, almost all teachers use the graphing calculator as it is part of the final examinations of mathematics, with the majority using either Texas Instruments or Casio. The use of the graphing calculator is also included in the textbooks used during classes, but this seems to be mostly limited to Texas

Instruments and Casio. This was also noted by one of the interviewees, who used the HP Prime. She said that they were unable to use some parts of the textbook as it did not cover how to do it with another type of graphing calculator. The same holds for the NumWorks graphing calculator, although this could also be because it has only just been approved for use at the final examinations, and hence textbooks have not yet included it. The lack of support by the textbooks could also be the reason why teachers mostly used the Texas Instruments and Casio graphing calculators in their classes, as it appeared to be easier for teachers to use what was given in the textbook, rather than preparing the curriculum materials covering the graphing calculator themselves.

Almost 80% of the teachers also used other digital tools than the graphing calculator, with GeoGebra being the most popular other digital tool, followed by Desmos. Both tools are mostly focused on the graphical aspect of the graphing calculator, where GeoGebra also offers functionalities for trigonometry in addition to simply plotting graphical representations of functions. Some textbooks also included chapters on the use of GeoGebra, but due to the limited time available for mathematics, these chapters were almost always skipped as they are not part of the final examinations program. Overall, the specific tools used by teachers is highly influenced by the regulations for the mathematics program, in addition to what is supported by textbooks.

*2. How are digital tools, in particular the graphing calculator, used by the teachers?* — To answer this question, we use the results of the questionnaire as well as parts of the interview. The ways the graphing calculator was used, was mostly dictated by the requirements set for the final examinations. Most of the time, students themselves used the graphing calculator when maxing exercises or taking tests. Most teachers explained themselves how to use a graphing calculator, but the difference was only marginally compared to letting students discover it themselves. We also found that the graphing calculator was mostly used for calculating numeric expressions, which a normal calculator could also do, and for visually representing functions or data. These corresponded to the parts of the final examinations for which the graphing calculator must be used. This was also given as the motivation for the use of the graphing calculator during the interviews. One interviewee even stated that were it not for the mandatory use during the final examinations, he/she would rather not use a graphing calculator in his/her lessons.

In contrast to the graphing calculator, the other digital tools were mostly used by the teachers during explanations. Students rarely used the tools themselves and they were never used during tests. This was said to be mostly due to the graphing calculator being mandatory for the final examinations. Students need to practice using it, so there is simply no time for using other digital tools during tests. Another reason for the lack of student use, is the requirement of another computational device, like a laptop or tablet. Not all schools currently have or use such devices during mathematics classes and the software does not always work well on every type of device. According to an interviewee, GeoGebra does not function properly on tablets and depending on the version of GeoGebra a student is using, some things will simply not work at all. In practice we thus mostly saw that teachers sometimes used digital tools like GeoGebra during classroom explanations, while students mostly used the graphing calculator when working on exercises or making tests. Again, as stated for the previous sub-question, the way of use was almost completely determined by the regulations set for the final examinations.

*3. What are teachers' views on the Dutch policy regarding digital tools, like the graphing calculator?* — We will answer this research question mostly based on the conducted interviews. As stated for the previous sub-questions, the examination mostly determines the tools that are being used during lessons by the students. The influence of the Dutch policy is therefore of importance not only for the mathematics exam, but also for mathematics during the lessons. Most teachers agreed with the allowance of the GC for the final exam. Teachers thought that there should be an allowed tool, to prevent students from 'drowning' in the calculations and to accommodate for asking questions that are more meaningful and interesting. Furthermore, teachers thought that it was too difficult to make other tools work, due to issues regarding licenses and management of devices, and therefore agreed with the GC being allowed.

As a side note, some teachers were convinced that these issues could be overcome, and there were also teachers that would prefer not having any tools at all, since according to them, they only tested how skillful the student could handle these tools. However, based on this research, this group was a minority. A last remark is that the most of the functions of the GC were redundant and that a more basic version would be sufficient. This solution might also reduce the costs on the long term, a concern multiple teachers voiced during the interviews.

*4. According to teachers, in which ways can digital tools, in particular the graphing calculator, be used to enhance student learning?* — This fourth sub-question is answered based on the results of the interviews. Some teachers used the GC extensively and other teachers used it only at the bare minimum to prepare the students for the final exam. Interesting was that both type of teachers mainly used the GC for plotting functions. As one interviewee stated, 'When a student is stuck [on a question], the first question I ask them is "Have you plotted the function?"'. According to this teacher, the GC enabled quick and easy, but also thorough function analysis. Student learning was also enhanced by the allowance of asking more meaningful questions, enabled by the GC. A larger part (60%) of the interviewees however, stated that the ease of plotting undermined the understanding of the function for the student. One of the teachers stated: ' "In theory, the student thinks about the function and experiences a learning process by plotting the function and comparing it with his thoughts. In practice, however, most students skip the first step and accept the plot without making connections with the form of the function."(Int D)' In conclusion, all teachers used the GC for plotting functions. Some teachers did this to enhance student learning, in their view, while other teachers don't think that usage of the GC enhances student learning at all. They mostly use the GC to teach the students how to (ab)use its functions to obtain the best results during examination.

*How did the COVID-19 pandemic influence the teachers' use of the graphing calculator and other digital tools?* — This last sub-question is answered by both the questionnaire and the interviews. Using the questionnaire, we found that very few teachers were influenced by the COVID-19 pandemic regarding their use of the GC and other digital tools. The interviewees confirmed this result during the interviews, so we can conclude that the use of the GC and other digital tools were barely changed by the pandemic.

*What are teachers' perceptions on the use of the graphing calculator and other digital tools for the enhancement of student learning in Dutch (upper) secondary mathematics education?* — We will first discuss the teachers' views on the graphing calculator and then their view on other digital tools. The perception on the use of the

GC of the Dutch teachers is very diverse. From the questionnaire answers, we can conclude that a majority of the teachers thinks that the GC provides a positive contribution, although most teachers are concerned about the effects on student learning. Many are worried that the calculation skills of the students suffer, and that even their understanding of mathematics has decreased. During the interviews, some teachers criticized the GC because students 'do not learn mathematics, but handling this small machine'. Other teachers focused on the benefits of 'not drowning in calculations'. The only opinion that a large part of the teachers shared, was that the GC was obsolete and that mathematics education is in need of an improved and possibly cheaper tool. We think that the main reason for this conclusion is the complexity of implementation of GCs. We believe that not enough teachers have the time and resources to find an optimal way to use the GC in their lessons. This conclusion is supported by Drijvers (2020).

The teachers were almost unanimous about their opinion on digital tools. A great majority of teachers used digital tools during classroom explanation. Here GeoGebra was by far the most used product. Although many teachers agreed that digital tools could be valuable to the lessons, students were rarely given the opportunity to experience with the tools themselves. The most common reason was that there was lack of time due to the current overloaded curriculum. Some teachers mentioned the lack of ICT-facilities such as laptops or other devices at their schools, which also prevented students form having access to other tools. In conclusion, according to mathematics teachers, digital tools have the potential to be of added value, but we find that the lack of facilities and the overloaded curriculum prevents students from using the tools themselves.

## Limitations

This study had some limitations. First of all, the 89 respondents for the questionnaire only formed a small part of the Dutch mathematics teachers. Also, the sample is biased, since we only reached mathematics teachers who received the news letter. Furthermore, teachers with a strong opinion on the GC and other tools were probably more likely to respond to the questionnaire. The second limitation was the limited amount of time for this research. In the next section we will provide some recommendations of how to conduct follow-up research based on this paper. The third limitation was a small error in the questionnaire as mentioned the section about the results. This has led to some confusion for our respondents and might have resulted in inconsistent results. A final limitation was that this research was conducted during the COVID-19-pandemic. In this time, the education in Dutch schools was in an online or hybrid form. Although, most teacher said that this did not influence their views regarding the GC and other tools, we are unsure about the influence.

## Further research

Due to the limitations of this research, there is still the possibility to conduct further research. Firstly, the research can be broadened to include more respondents to obtain better data. Further research can also be conducted by the CvTE, since one interviewee pointed out that they already had plans for more research. Unfortunately, they did not continue their research, while most teachers felt that it would be necessary for the revision of the curriculum. Currently, the GC is discussed again, because someone sent a complaint letter to the government, in which he stated that he already has to buy a fourth GC for his children, due to the ever changing requirements. The Dutch minister of education has said to look into it.(NOS, 2021)

# References

Chyung, S. Y. Y., Kennedy, M., & Campbell, I. (2018, May). Evidence-based survey design: The use of ascending or descending order of likert-type response options. *Performance Improvement*, *57*(9), 9–16. Retrieved from https://doi.org/10.1002/pfi.21800

cTWO. (2008). *Use to learn; naar een zinvolle integratie van ict in het wiskundeonderwijs* (Tech. Rep.). commissie Toekomst WiskundeOnderwijs.

Curriculum.nu. (n.d.-a). *Curriculum.nu - het proces in stappen.* Retrieved 2021-06-06, from https://www.curriculum.nu/het-proces/in-stappen/

Curriculum.nu. (n.d.-b). *Wetenschappelijke commissie adviseert over de landelijke bijstelling van het curriculum po en vo.* Retrieved 2021-04-12, from https://www.curriculumcommissie.nl/actueel-berichten/wetenschappelijke-commissie-adviseert-over-de-landelijke-bijstelling-van-het-curriculum-po-en-vo

CvTE-commissie. (2018). *Toekomstbestendig toetsen; ict bij de centrale examens wiskunde havo/vwo* (Tech. Rep.). College voor Toetsen en Examens.

Doerr, H. M., & Zangor, R. (2000). Creating meaning for and with the graphing calculator. *Educational Studies in Mathematics*, *41*, 143-146. Retrieved from https://doi.org/10.1023/A:1003905929557

Drijvers, P. (2020). Digital Tools in Dutch Mathematics Education: A Dialectic Relationship. In M. Van den Heuvel-Panhuizen (Ed.), *National Reflections on the Netherlands Didactics of Mathematics: Teaching and Learning in the Context of Realistic Mathematics Education* (pp. 177–195). Cham: Springer International Publishing. Retrieved from https://doi.org/10.1007/978-3-030-33824-4_10

Ellington, A. J. (2003). A meta-analysis of the effects of calculators on students' achievement and attitude levels in precollege mathematics classes. *Journal for Research in Mathematics Education*, *34*(5), 433–463. Retrieved from http://www.jstor.org/stable/30034795

Ellington, A. J. (2006). The effects of non-cas graphing calculators on student achievement and attitude levels in mathematics: A meta-analysis. *School Science and Mathematics*, *106*(1), 16-26. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1949-8594.2006.tb18067.x

Hendrikse, P. J. J. (2020, July 6). *Regeling toegestane hulpmiddelen voor de centrale examens vo 2022.* Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (Stcrt. 2020, 35259)

Hennessy, S. (1999). The potential of portable technologies for supporting graphing investigations. *British Journal of Educational Technology*, *30*(1), 57-60. Retrieved from https://bera-journals.onlinelibrary.wiley.com/doi/abs/10.1111/1467-8535.00090

Hiebert, J., & Carpenter, T. P. (1992). Learning and teaching with understanding. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning: A project of the national council of teachers of mathematics* (p. 65-97). Macmillan Publishing Co, Inc.

Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis. *Computers & Education*, *153*, 103897. Retrieved from http://www.sciencedirect.com/science/article/pii/S0360131520300968

Hohenwarter, M. (2002). *GeoGebra: Ein Softwaresystem für dynamische Geometrie und Algebra der Ebene* (Unpublished master's thesis). Paris Lodron University, Salzburg, Austria. ((In German.))

Karadeniz, I. (2015, January). UCSMP Teachers' Perspectives when Using Graphing Calculators in Advanced Mathematics. *Graduate Theses and Dissertations*. Retrieved from https://scholarcommons.usf.edu/etd/5712

Kock, Z.-j., & Pepin, B. (2019). Secondary school mathematics teachers' selection and use of resources. In U. Jankvist, M. Van den Heuvel-Panhuizen, & M. Veldhuis (Eds.), *Proceedings of the eleventh congress of the european society for research in mathematics education.* Freudenthal Group & Freudenthal Institute, Utrecht University and ERME. (11th Congress of the European Society for Research in Mathematics Education, CERME11 ; Conference date: 06-02-2019 Through 10-02-2019)

Koopmans, J. (2018). *Stukje bij bitje - onderzoeksrapport: De inzet van digitale leermiddelen in het voortgezet onderwijs* (Tech. Rep.). Landelijk Aktie Komitee Scholieren. Retrieved from https://www.laks.nl/wp-content/uploads/2018/09/Stukje-bij-Bitje-rapport-digitale-leermiddelen.pdf

Leinhardt, G., Zaslavsky, O., & Stein, M. K. (1990). Functions, graphs, and graphing: Tasks, learning, and teaching. *Review of Educational Research*, *60*(1), 1-64. Retrieved from https://doi.org/10.3102/00346543060001001

Lyke, J. A., & Young, A. J. K. (2006). Cognition in context: Students' perceptions of classroom goal structures and reported cognitive strategy use in the college classroom. *Research in Higher Education*, *47*(4), 477–490. Retrieved from http://www.jstor.org/stable/40197413

Molenje, L. (2012, May). High School Teachers' Use of Graphing Calculators When Teaching Linear and Quadratic Functions: Professed Beliefs and Observed Practice. *Teaching and Leadership - Dissertations*. Retrieved from https://surface.syr.edu/tl_etd/239

National Research Council. (2001). *Adding it up: Helping children learn mathematics* (J. Kilpatrick, J. Swafford, & B. Findell, Eds.). Washington, DC: The National Academies Press. Retrieved from https://www.nap.edu/catalog/9822/adding-it-up-helping-children-learn-mathematics

NOS. (2021, August). *Boze vader krijgt kamer mee in strijd tegen dure rekenmachine op school.* Retrieved from https://nos.nl/artikel/2394273-boze-vader-krijgt-kamer-mee-in-strijd-tegen-dure-rekenmachine-op-school

Penglase, M., & Arnold, S. (1996, Apr 01). The graphics calculator in mathematics education: A critical review of recent research. *Mathematics Education Research Journal*, *8*(1), 58-90. Retrieved from https://doi.org/10.1007/BF03355481

Perkins, K., Adams, W., Dubson, M., Finkelstein, N., Reid, S., Wieman, C., & LeMaster, R. (2006, January). PhET: Interactive simulations for teaching and learning physics. *The Physics Teacher*, *44*(1), 18–23. Retrieved from https://doi.org/10.1119/1.2150754

Rillero, P. (2016). Deep conceptual learning in science and mathematics: Perspectives of teachers and administrators. *The Electronic Journal of Science Education*, *20*, 14-31.

Slob, A. (2020, Jun 10). *Bijstelling en aanscherping en vervolgproces actualisatie curriculum primair en voortgezet onderwijs [kamerbrief].* Retrieved from https://www.rijksoverheid.nl/onderwerpen/toekomst-onderwijs/documenten/kamerstukken/2020/06/10/bijstelling-en-aanscherping-en-vervolgproces-actualisatie-curriculum-primair-en-voortgezet-onderwijs

Sue, J.-W., & David, P. (2005). Ebook: Teaching secondary mathematics with ict. In (chap. 8). Open University Press. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=nlebk&AN=233983&site=ehost-live

van Bijsterveldt-Vliegenthart, J. M. (2012, Apr 05). *Gebruik rekenmachine bij toetsen in het basisonderwijs en examens in het voortgezet onderwijs [kamerbrief].* Retrieved from https://www.tweedekamer.nl/kamerstukken/brieven_regering/detail?id=2012Z07214&did=2012D15372

Vernieuwingscommissie wiskunde cTWO. (2012). *Denken & doen; wiskunde op havo en vwo per 2015* (Tech. Rep.). commissie Toekomst WiskundeOnderwijs.

Waits, B., & Demana, F. D. (2000). Calculators in mathematics teaching and learning: Past, present, and future. part 2: Technology and the mathematics classroom..

WiskundE-brief. (n.d.). *De wiskunde-brief op het web.* Retrieved 2021-06-13, from https://www.wiskundebrief.nl/

# Appendices

## Appendix A: Questionnaire items

### Toestemming verzamelen gegevens

In verband met de AVG dienen we toestemming van u te krijgen voor het verzamelen van uw gegevens met deze enquête. In dit document staat beschreven wat wij doen, waarom wij het doen, hoe wij omgaan met uw data en meer. Wij vragen u dit document door te nemen en hieronder akkoord te gaan met het verzamelen van uw gegevens.

1. Vul hieronder in dat u toestemming geeft voor het verzamelen van uw gegevens voor dit onderzoek.
   ☐ Ik geef toestemming voor het verzamelen van mijn gegevens

### Deel 1 - Algemene informatie

2. Wat is uw leeftijd?
   ○ 20-30 jaar
   ○ 31-40 jaar
   ○ 41-55 jaar
   ○ >55 jaar

3. Hoeveel jaar bent u al werkzaam als docent in het voortgezet onderwijs?
   ○ 0-5 jaar
   ○ 5-10 jaar
   ○ 10-20 jaar
   ○ >20 jaar

4. Waar heeft u uw meest recente onderwijsbevoegdheid gehaald?
   - ○ Hbo educatieve bacheloropleiding
   - ○ Hbo educatieve masteropleiding
   - ○ Wo educatieve bacheloropeleiding
   - ○ Wo educatieve (post)masteropleiding
   - ○ Ik bezit geen onderwijsbevoegdheid wiskunde
   - ○ Zeg ik liever niet
   - ○ Anders ____________

5. Aan welke bovenbouw klassen wiskunde heeft u de afgelopen 3 jaar les gegeven?
   Meerdere antwoorden mogelijk
   - ☐ Havo wiskunde A
   - ☐ Havo wiskunde B
   - ☐ Havo wsikunde D
   - ☐ Vwo wiskunde A
   - ☐ Vwo wiskunde B
   - ☐ Vwo wiskunde C
   - ☐ Vwo wiskunde D
   - ☐ Anders ____________

6. Welke lesmethode gebruikt u vooral bij de wiskundelessen in de bovenbouw?
   - ○ Getal en ruimte
   - ○ Moderne wiskunde
   - ○ Wagenische methode
   - ○ MathPlus
   - ○ Ik gebruik geen methode
   - ○ Anders ____________

## Deel 2 - Grafische rekenmachine

De komende vragen gaan over het gebruik van de grafische rekenmachine (GR). Voor dit onderzoek focussen wij ons op het onderwerp fucnties en grafieken, omdat hier voornamelijk nog gebruik wordt gemaakt van de grafische rekenmachine. Ga bij onderstaande vragen uit van lessen met onderwerp functies en grafieken.

7. Heeft u in de afgelopen 3 jaar les geven over het onderwerp functies en grafieken?
   ○ Ja
   ○ Nee

8. Maakt u gebruik van een grafische rekenmachine bij uw lessen over functies en grafieken?
   ○ Ja
   ○ Nee

9. Van welke grafische rekenmachine (merk) maakt u dan voornamelijk gebruik?
   ○ Texas Instruments
   ○ Casio
   ○ HP Prime
   ○ NumWorks
   ○ Anders ______

10. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

| | Nooit | Zelden | Soms | Vaak | Altijd |
|---|---|---|---|---|---|
| (a) Ik gebruik de GR tijdens de klassikale uitleg. | ○ | ○ | ○ | ○ | ○ |
| (b) Ik gebruik de GR bij het bespreken van opgaven. | ○ | ○ | ○ | ○ | ○ |
| (c) Leerlingen gebruiken de GR bij het maken van opgaven. | ○ | ○ | ○ | ○ | ○ |
| (d) Leerlingen gebruiken de GR bij het maken van toetsen. | ○ | ○ | ○ | ○ | ○ |

11. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

| | Nooit | Zelden | Soms | Vaak | Altijd |
|---|---|---|---|---|---|
| (a) Ik geef klassikaal uitleg over hoe de GR werkt. | ○ | ○ | ○ | ○ | ○ |
| (b) Ik laat leerlingen zelf ontdekken hoe de GR werkt. | ○ | ○ | ○ | ○ | ○ |
| (c) Ik geef klassikaal uitleg over concepten en begrippen m.b.v. de GR. | ○ | ○ | ○ | ○ | ○ |
| (d) Ik laat leerlingen zelf concepten en begrippen ontdekken m.b.v. de GR. | ○ | ○ | ○ | ○ | ○ |

12. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

| | Nooit | Zelden | Soms | Vaak | Altijd |
|---|---|---|---|---|---|
| (a) Leerlingen gebruiken de GR voor het uitrekenen van numerieke expressies. | ○ | ○ | ○ | ○ | ○ |
| (b) Leerlingen gebruiken de GR om functies of data visueel weer te geven. | ○ | ○ | ○ | ○ | ○ |
| (c) Leerlingen gebruiken de GR om data te verzamelen en te analyseren. | ○ | ○ | ○ | ○ | ○ |
| (d) Leerlingen gebruiken de GR om ideeën of antwoorden te controleren. | ○ | ○ | ○ | ○ | ○ |

13. Geef aan in hoeverre u het eens bent met de volgende stellingen:

| | Zeer mee oneens | Mee oneens | Neutraal | Mee eens | Zeer mee eens |
|---|---|---|---|---|---|
| (a) De GR heeft een positieve bijdrage aan het wiskundeonderwijs. | ○ | ○ | ○ | ○ | ○ |
| (b) De GR zou een grotere rol moeten krijgen in het wiskundeonderwijs. | ○ | ○ | ○ | ○ | ○ |
| (c) De GR leidt tot de verminderde rekenvaardigheden van leerlingen in het wiskundeonderwijs. | ○ | ○ | ○ | ○ | ○ |
| (d) Ik kan goed overweg met (de functies van) de GR. | ○ | ○ | ○ | ○ | ○ |
| (e) De GR is een handige tool voor visualisatie van data of functies. | ○ | ○ | ○ | ○ | ○ |
| (f) De GR helpt leerlingen om wiksunde beter te begrijpen. | ○ | ○ | ○ | ○ | ○ |
| (g) Het gebruik van de GR leidt tot betere cijfers bij de leerlingen. | ○ | ○ | ○ | ○ | ○ |
| (h) De GR helpt leerlingen met het ontwikkelen van probleemoplossende vaardigheden. | ○ | ○ | ○ | ○ | ○ |

## Deel 3 - Andere digitale middelen

De komende vragen gaan over het gebruik van andere digitale middelen, anders dan de (grafische) rekenmachine. Onder deze digitale middelen verstaan we middelen die worden gebruikt ter vervangen of versterking van (delen van) de grafische rekenmachine. Denk hierbij aan het grafisch weergeven van grafieken, maken van tabellen of berekeningen met functies. Ga wederom bij onderstaande vragen uit van lessen met als onderwerp functies en grafieken.

14. Maakt u gebruik van andere digitale middelen, anders dan de (grafische) rekenmachine?
    Bijv. applets of GeoGebra.
    ○ Ja
    ○ Nee

15. Van welke andere digitale middelen maakt u dan gebruik?
    Meerdere antwooren mogelijk.
    ☐ GeoGebra
    ☐ Desmos
    ☐ ClassPad
    ☐ WolframAlpha
    ☐ Applets (bijv. PhET)
    ☐ Apps op telefoon
    ☐ Anders ________

16. Welk andere digitale middele hiervan gebruikt u het meest?
    ○ GeoGebra
    ○ Desmos
    ○ ClassPad
    ○ WolframAlpha
    ○ Applets (bijv. PhET)
    ○ Apps op telefoon
    ○ Anders ________

Beantwoord de komende vraagen over het digitale middel dat u het meest gebruikt, deze wordt in de vragen telkens 'het hulpmiddel' genoemd:

17. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

| | Nooit | Zelden | Soms | Vaak | Altijd |
|---|---|---|---|---|---|
| (a) Ik gebruik het hulpmiddel tijdens de klassikale uitleg. | ○ | ○ | ○ | ○ | ○ |
| (b) Ik gebruik het hulpmiddel bij het bespreken van opgaven. | ○ | ○ | ○ | ○ | ○ |
| (c) Leerlingen gebruiken het hulpmiddel bij het maken van opgaven. | ○ | ○ | ○ | ○ | ○ |
| (d) Leerlingen gebruiken het hulpmiddel bij het maken van toetsen. | ○ | ○ | ○ | ○ | ○ |

18. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

| | Nooit | Zelden | Soms | Vaak | Altijd |
|---|---|---|---|---|---|
| (a) Ik geef klassikaal uitleg over hoe het hulpmiddel werkt. | ○ | ○ | ○ | ○ | ○ |
| (b) Ik laat leerlingen zelf ontdekken hoe het hulpmiddel werkt. | ○ | ○ | ○ | ○ | ○ |
| (c) Ik geef klassikaal uitleg over concepten en begrippen m.b.v. het hulpmiddel. | ○ | ○ | ○ | ○ | ○ |
| (d) Ik laat leerlingen zelf concepten en begrippen ontdekken m.b.v. het hulpmiddel. | ○ | ○ | ○ | ○ | ○ |

19. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

| | Nooit | Zelden | Soms | Vaak | Altijd |
|---|---|---|---|---|---|
| (a) Leerlingen gebruiken het hulpmiddel voor het uitrekenen van numerieke expressies. | ○ | ○ | ○ | ○ | ○ |
| (b) Leerlingen gebruiken het hulpmiddel om functies of data visueel weer te geven. | ○ | ○ | ○ | ○ | ○ |
| (c) Leerlingen gebruiken het hulpmiddel om data te verzamelen en te analyseren. | ○ | ○ | ○ | ○ | ○ |
| (d) Leerlingen gebruiken het hulpmiddel om ideeën of antwoorden te controleren. | ○ | ○ | ○ | ○ | ○ |

20. Geef aan in hoeverre u het eens bent met de volgende stellingen:

| | Zeer mee oneens | Mee oneens | Neutraal | Mee eens | Zeer mee eens |
|---|---|---|---|---|---|
| (a) Het hulpmiddel heeft een positieve bijdrage aan het wiskundeonderwijs. | ○ | ○ | ○ | ○ | ○ |
| (b) Het hulpmiddel zou een grotere rol moeten krijgen in het wiskundeonderwijs. | ○ | ○ | ○ | ○ | ○ |
| (c) Het hulpmiddel leidt tot de verminderde rekenvaardigheden van leerlingen in het wiskundeonderwijs. | ○ | ○ | ○ | ○ | ○ |
| (d) Ik kan goed overweg met (de functies van) het hulpmiddel. | ○ | ○ | ○ | ○ | ○ |
| (e) Het hulpmiddel is een handige tool voor visualisatie van data of functies. | ○ | ○ | ○ | ○ | ○ |
| (f) Het hulpmiddel helpt leerlingen om wiksunde beter te begrijpen. | ○ | ○ | ○ | ○ | ○ |
| (g) Het gebruik van het hulpmiddel leidt tot betere cijfers bij de leerlingen. | ○ | ○ | ○ | ○ | ○ |
| (h) Het hulpmiddel helpt leerlingen met het ontwikkelen van probleemoplossende vaardigheden. | ○ | ○ | ○ | ○ | ○ |

## Deel 4 - Invloed van COVID-19

Hieronder enkele vragen over de invloed van COVID-19 en de online lessen op het gebruik van de grafische rekenmachine en andere hulpmiddelen.

21. Hoe gebruikt u de grafische rekenmachine in de periode van het online onderwijs vergeleken met onderwijs op school?

| | Veel minder | Minder | Evenveel | Meer | Veel meer |
|---|---|---|---|---|---|
| (a) Bij het klassikaal uitleggen van de stof. | ○ | ○ | ○ | ○ | ○ |
| (b) Bij het behandelen van opgaven. | ○ | ○ | ○ | ○ | ○ |
| (c) Bij het maken van de opgaven door leerlingen. | ○ | ○ | ○ | ○ | ○ |
| (d) Bij het maken van toetsen. | ○ | ○ | ○ | ○ | ○ |

22. Hoe gebruikt u digitale hulpmiddelen in de periode van het online onderwijs vergeleken met onderwijs op school?

| | Veel minder | Minder | Evenveel | Meer | Veel meer |
|---|---|---|---|---|---|
| (a) Bij het klassikaal uitleggen van de stof. | ○ | ○ | ○ | ○ | ○ |
| (b) Bij het behandelen van opgaven. | ○ | ○ | ○ | ○ | ○ |
| (c) Bij het maken van de opgaven door leerlingen. | ○ | ○ | ○ | ○ | ○ |
| (d) Bij het maken van toetsen. | ○ | ○ | ○ | ○ | ○ |

## Einde vragenlijst en vervolginterview

Dit is het einde van de vragenlijst. Hartelijk dan voor uw bijdrage aan ons onderzoek.

Voor ons onderzoek willen we ook een aantal vervolginterviews houden met docenten. Indien u interesse heeft voor dit vervolginterview, kunt u hieronder uw e-mail adres achterlaten. Uw e-mail adres wordt alleen gebruikt om éénmalig met u contact op te nemen voor het vervolginterview.

23. Wat is uw e-mail adres?

24. Heeft u nog op- of aanmerkingen op de enquête zelf? Of wilt u nog wat kwijt over digitale hulpmiddelen bij de wiskundelessen? Dan kunt u dat hier invullen.

# Appendix B: Results of questionnaire

## Deel 1 - Algemene informatie

2. Wat is uw leeftijd?

Table 3: Results of question 2

| Option | Frequency | Percent |
|---|---|---|
| 20-30 jaar | 4 | 4.6 |
| 31-40 jaar | 13 | 14.9 |
| 41-55 jaar | 37 | 42.5 |
| >55 jaar | 33 | 37.9 |

3. Hoeveel jaar bent u al werkzaam als docent in het voortgezet onderwijs?

Table 4: Results of question 3

| Option | Frequency | Percent |
|---|---|---|
| 0-5 jaar | 8 | 9.2 |
| 5-10 jaar | 13 | 14.9 |
| 10-20 jaar | 34 | 39.1 |
| >20 jaar | 32 | 36.8 |

4. Waar heeft u uw meest recente onderwijsbevoegdheid gehaald?

Table 5: Results of question 4

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| Hbo educatieve bacheloropleiding | 8 | 9.2 |
| Hbo educatieve masteropleiding | 33 | 37.9 |
| Wo educatieve bacheloropleiding | 1 | 1.1 |
| Wo educatieve (post)masteropleiding | 40 | 46.0 |
| Ik bezit geen onderwijsbevoegdheid wiskunde | 1 | 1.1 |
| Zeg ik liever niet | 0 | 0.0 |
| Anders | 4 | 4.6 |

5. Aan welke bovenbouw klassen wiskunde heeft u de afgelopen 3 jaar les gegeven? Meerdere antwoorden mogelijk

Table 6: Results of question 5

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| Havo wiskunde A | 67 | 77.0 |
| Havo wiskunde B | 61 | 70.1 |
| Havo wiskunde D | 17 | 19.5 |
| Vwo wiskunde A | 67 | 77.0 |
| Vwo wiskunde B | 69 | 79.3 |
| Vwo wiskunde C | 30 | 34.5 |
| Vwo wiskunde D | 36 | 41.4 |
| Anders | 0 | 0.0 |

6. Welke lesmethode gebruikt u vooral bij de wiskundelessen in de bovenbouw?

Table 7: Results of question 6

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| Getal en ruimte | 62 | 71.3 |
| Moderne wiskunde | 22 | 25.3 |
| Wagenische methode | 3 | 3.4 |
| Mathplus | 0 | 0.0 |
| Ik gebruik geen methode | 0 | 0.0 |
| Anders | 0 | 0.0 |

## Deel 2 - Grafische rekenmachine

7. Heeft u in de afgelopen 3 jaar les gegeven over het onderwerp functies en grafieken?

Table 8: Results of question 7

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| Ja | 87 | 100.0 |
| Nee | 0 | 0.0 |

8. Maakt u gebruik van een grafische rekenmachine bij uw lessen over functies en grafieken?

Table 9: Results of question 8

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| Ja | 86 | 98.9 |
| Nee | 1 | 1.1 |

9. Van welke rekenmachine (merk) maakt u dan voornamelijk gebruik?

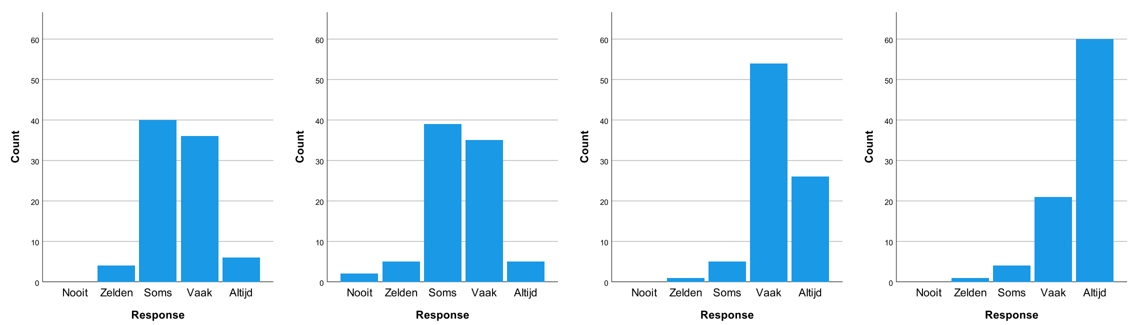
Table 10: Results of question 9

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| Texas Instruments | 49 | 57.0 |
| Casio | 33 | 38.4 |
| HP Prime | 4 | 4.7 |
| NumWorks | 0 | 0.0 |

10. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

Table 11: Results of question 10

| Item | Median | Mean | STD |
|---|---|---|---|
| (a) Ik gebruik de GR tijdens de klassikale uitleg. | 3 | 3.51 | 0.699 |
| (b) Ik gebruik de GR bij het bespreken van opgaven. | 3 | 3.42 | 0.789 |
| (c) Leerlingen gebruiken de GR bij het maken van opgaven. | 4 | 4.22 | 0.602 |
| (d) Leerlingen gebruiken de GR bij het maken van toetsen. | 5 | 4.63 | 0.633 |



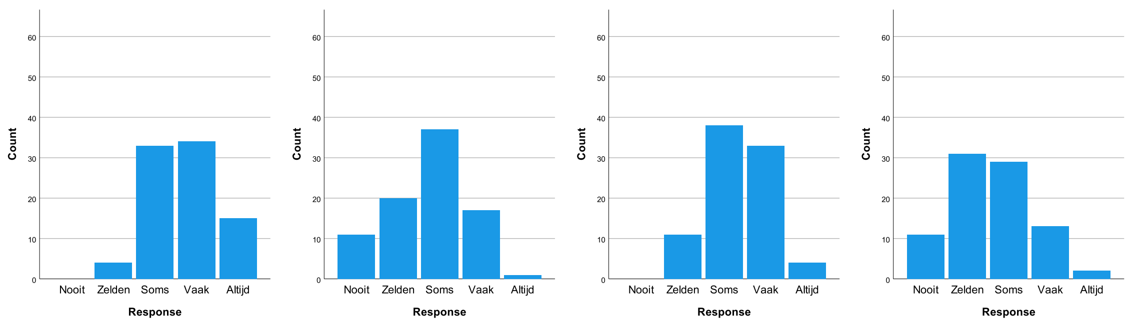

(a) Item a (b) Item b (c) Item c (d) Item d

Figure 1: Results of question 10

11. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

Table 12: Results of question 11

| **Item** | **Median** | **Mean** | **STD** |
|---|---|---|---|
| (a) Ik geef klassikaal uitleg over hoe de GR werkt. | 4 | 3.70 | 0.813 |
| (b) Ik laat leerlingen zelf ontdekken hoe de GR werkt. | 3 | 2.73 | 0.963 |
| (c) Ik geef klassikaal uitleg over concepten en begrippen m.b.v. de GR. | 3 | 3.35 | 0.763 |
| (d) Ik laat leerlingen zelf concepten en begrippen ontdekken m.b.v. de GR. | 3 | 2.58 | 0.976 |



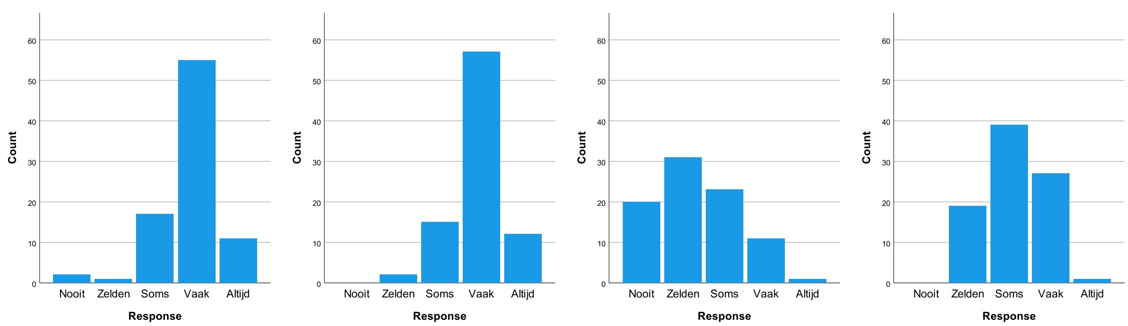

(a) Item a (b) Item b (c) Item c (d) Item d

Figure 2: Results of question 11

12. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

Table 13: Results of question 12

| **Item** | **Median** | **Mean** | **STD** |
|---|---|---|---|
| (a) Leerlingen gebruiken de GR voor het uitrekenen van numerieke expressies. | 4 | 3.84 | 0.749 |
| (b) Leerlingen gebruiken de GR om functies of data visueel weer te geven. | 4 | 3.92 | 0.636 |
| (c) Leerlingen gebruiken de GR om data te verzamelen en te analyseren. | 2 | 2.33 | 1.011 |
| (d) Leerlingen gebruiken de GR om ideeën of antwoorden te controleren. | 3 | 3.12 | 0.758 |



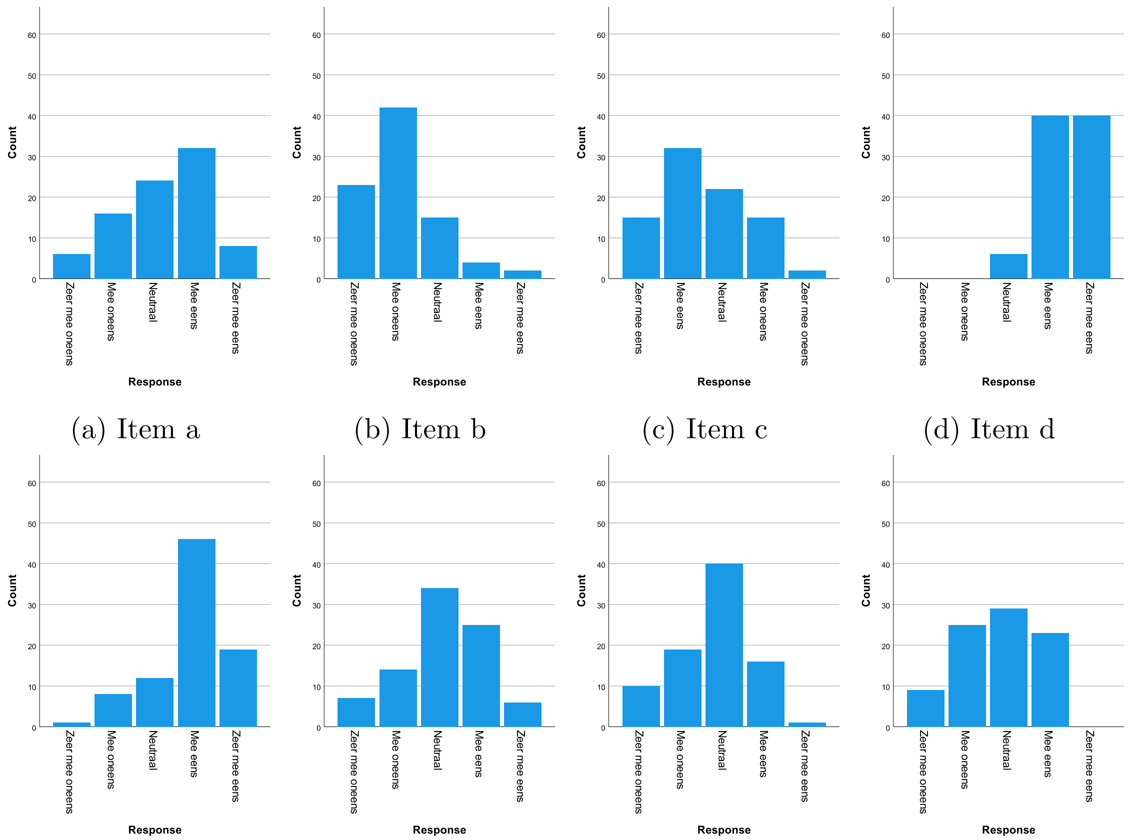

(a) Item a (b) Item b (c) Item c (d) Item d

Figure 3: Results of question 12

13. Geef aan in hoeverre u het eens bent met de volgende stellingen:

Table 14: Results of question 13

| **Item** | **Median** | **Mean** | **STD** |
|---|---|---|---|
| (a) De GR heeft een positieve bijdrage aan het wiskundeonderwijs. | 3 | 3.23 | 1.081 |
| (b) De GR zou een grotere rol moeten krijgen in het wiskundeonderwijs. | 2 | 2.07 | 0.918 |
| (c) De GR leidt tot de verminderde rekenvaardigheden van leerlingen in het wiskundeonderwijs. | 2 | 2.50 | 1.049 |
| (d) Ik kan goed overweg met (de functies van) de GR. | 4 | 4.40 | 0.619 |
| (e) De GR is een handige tool voor visualisatie van data of functies | 4 | 3.86 | 0.910 |
| (f) De GR helpt leerlingen om wiksunde beter te begrijpen. | 3 | 3.10 | 1.029 |
| (g) Het gebruik van de GR leidt tot betere cijfers bij de leerlingen. | 3 | 2.76 | 0.932 |
| (h) De GR helpt leerlingen met het ontwikkelen van probleemoplossende vaardigheden. | 3 | 2.77 | 0.966 |




(a) Item a (b) Item b (c) Item c (d) Item d

(e) Item e (f) Item f (g) Item g (h) Item h

Figure 4: Results of question 13

## Deel 3 - Andere digitale middelen

14. Maakt u gebruik van andere digitale middelen, anders dan de (grafische) rekenmachine?
    Bijv. applets of GeoGebra.

Table 15: Results of question 14

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| Ja | 18 | 20.7 |
| Nee | 69 | 79.3 |

15. Van welke andere digitale middelen maakt u dan gebruik?
    Meerdere antwooren mogelijk.

Table 16: Results of question 15

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| GeoGebra | 66 | 95.7 |
| Desmos | 12 | 17.4 |
| ClassPad | 0 | 0.0 |
| WolframAlpha | 9 | 13.0 |
| Applets (bijv. Phet) | 5 | 4.5 |
| Apps op telefoon | 9 | 13.0 |
| Anders | 10 | 14.5 |

16. Welk andere digitale middele hiervan gebruikt u het meest?

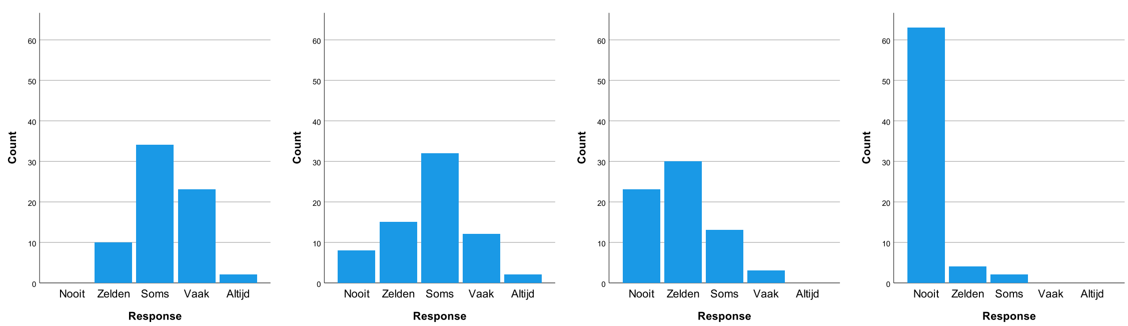
Table 17: Results of question 16

| **Option** | **Frequency** | **Percent** |
|---|---|---|
| GeoGebra | 56 | 81.2 |
| Desmos | 7 | 10.0 |
| ClassPad | 0 | 0.0 |
| WolframAlpha | 0 | 0.0 |
| Applets (bijv. Phet) | 0 | 0.0 |
| Apps op telefoon | 1 | 1.4 |
| Anders | 5 | 7.2 |

17. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

Table 18: Results of question 17

| **Item** | **Median** | **Mean** | **STD** |
|---|---|---|---|
| (a) Ik gebruik het hulpmiddel tijdens de klassikale uitleg. | 3 | 3.25 | 0.736 |
| (b) Ik gebruik het hulpmiddel bij het bespreken van opgaven. | 3 | 2.78 | 0.968 |
| (c) Leerlingen gebruiken het hulpmiddel bij het maken van opgaven. | 2 | 1.94 | 0.838 |
| (d) Leerlingen gebruiken het hulpmiddel bij het maken van toetsen. | 1 | 1.12 | 0.404 |



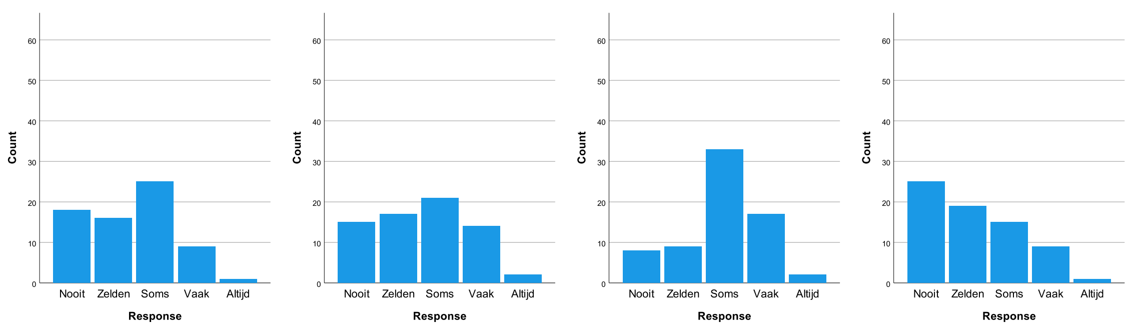

(a) Item a (b) Item b (c) Item c (d) Item d

Figure 5: Results of question 17

18. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

Table 19: Results of question 18

| **Item** | **Median** | **Mean** | **STD** |
|---|---|---|---|
| (a) Ik geef klassikaal uitleg over hoe het hulpmiddel werkt. | 3 | 2.41 | 1.062 |
| (b) Ik laat leerlingen zelf ontdekken hoe het hulpmiddel werkt. | 3 | 2.58 | 1.130 |
| (c) Ik geef klassikaal uitleg over concepten en begrippen m.b.v. het hulpmiddel. | 3 | 2.94 | 0.983 |
| (d) Ik laat leerlingen zelf concepten en begrippen ontdekken m.b.v. het hulpmiddel. | 2 | 2.16 | 1.106 |



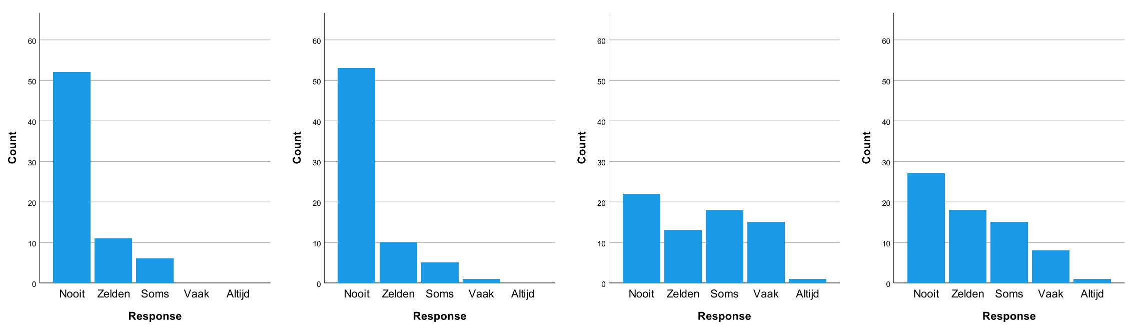

(a) Item a (b) Item b (c) Item c (d) Item d

Figure 6: Results of question 18

19. Geef van onderstaande situaties aan hoe vaak ze voorkomen in uw lessen:

Table 20: Results of question 19

| **Item** | **Median** | **Mean** | **STD** |
|---|---|---|---|
| (a) Leerlingen gebruiken het hulpmiddel voor het uitrekenen van numerieke expressies. | 1 | 1.33 | 0.634 |
| (b) Leerlingen gebruiken het hulpmiddel om functies of data visueel weer te geven. | 1 | 1.33 | 0.679 |
| (c) Leerlingen gebruiken het hulpmiddel om data te verzamelen en te analyseren. | 2 | 2.42 | 1.193 |
| (d) Leerlingen gebruiken het hulpmiddel om ideeën of antwoorden te controleren. | 2 | 2.10 | 1.100 |



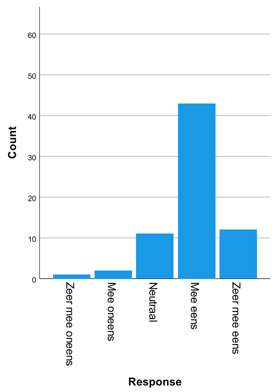

(a) Item a (b) Item b (c) Item c (d) Item d

Figure 7: Results of question 19

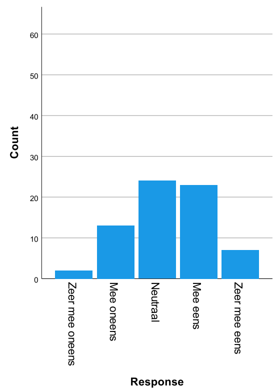
20. Geef aan in hoeverre u het eens bent met de volgende stellingen:

Table 21: Results of question 20

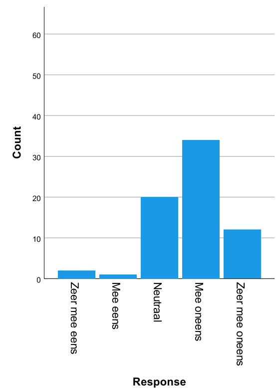
| **Item** | **Median** | **Mean** | **STD** |
|---|---|---|---|
| (a) Het hulpmiddel heeft een positieve bijdrage aan het wiskundeonderwijs. | 4 | 3.91 | 0.762 |
| (b) Het hulpmiddel zou een grotere rol moeten krijgen in het wiskundeonderwijs. | 3 | 3.29 | 0.987 |
| (c) Het hulpmiddel leidt tot de verminderde rekenvaardigheden van leerlingen in het wiskundeonderwijs. | 4 | 3.77 | 0.860 |
| (d) Ik kan goed overweg met (de functies van) het hulpmiddel. | 4 | 3.80 | 0.948 |
| (e) Het hulpmiddel is een handige tool voor visualisatie van data of functies. | 4 | 4.09 | 0.919 |
| (f) Het hulpmiddel helpt leerlingen om wiksunde beter te begrijpen. | 4 | 3.93 | 0.754 |
| (g) Het gebruik van het hulpmiddel leidt tot betere cijfers bij de leerlingen. | 3 | 2.94 | 0.745 |
| (h) Het hulpmiddel helpt leerlingen met het ontwikkelen van probleemoplossende vaardigheden. | 3 | 3.10 | 0.825 |



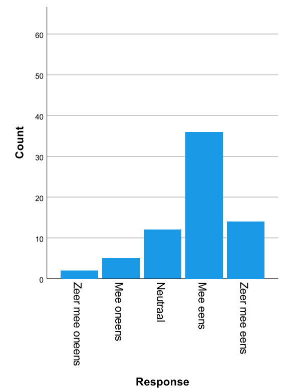

(a) Item a



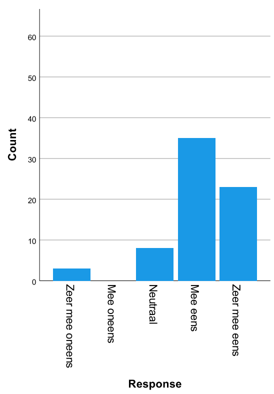

(b) Item b



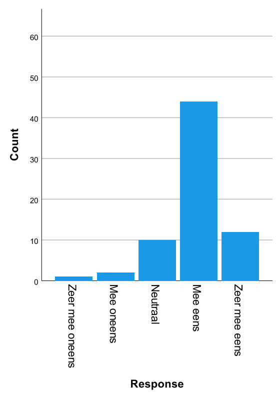

(c) Item c



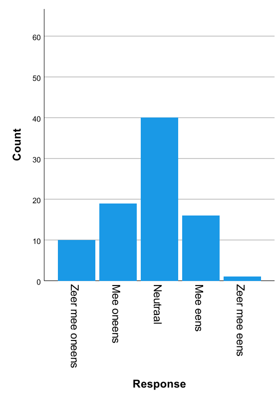

(d) Item d



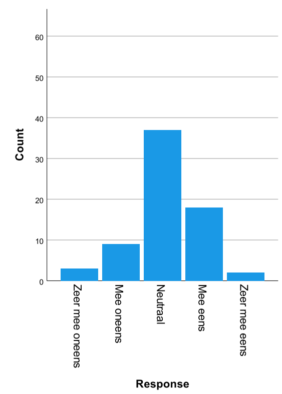

(e) Item e




(f) Item f




(g) Item g




(h) Item h

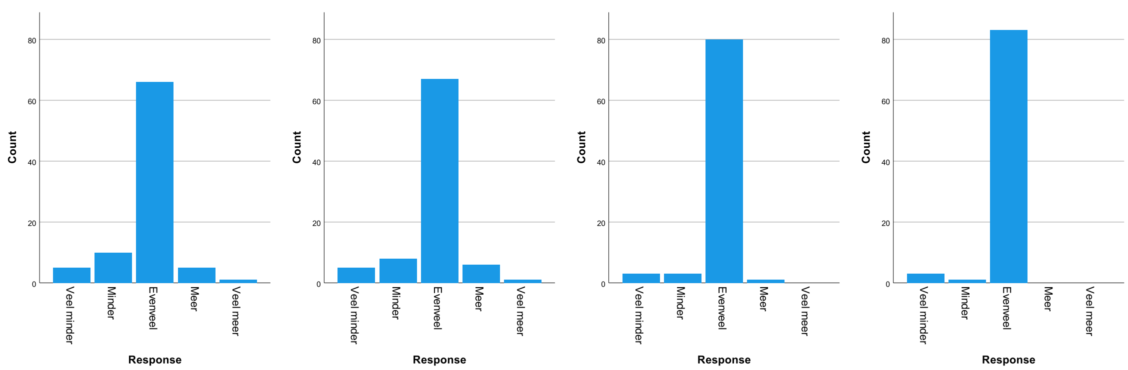
Figure 8: Results of question 20

## Deel 4 - Invloed van COVID-19

21. Hoe gebruikt u de grafische rekenmachine in de periode van het online onderwijs vergeleken met onderwijs op school?

Table 22: Results of question 21

| **Item** | **Median** | **Mean** | **STD** |
|---|---|---|---|
| (a) Bij het klassikaal uitleggen van de stof. | 3 | 2.85 | 0.656 |
| (b) Bij het behandelen van opgaven. | 3 | 2.89 | 0.655 |
| (c) Bij het maken van de opgaven door leerlingen. | 3 | 2.91 | 0.421 |
| (d) Bij het maken van toetsen. | 3 | 2.92 | 0.380 |



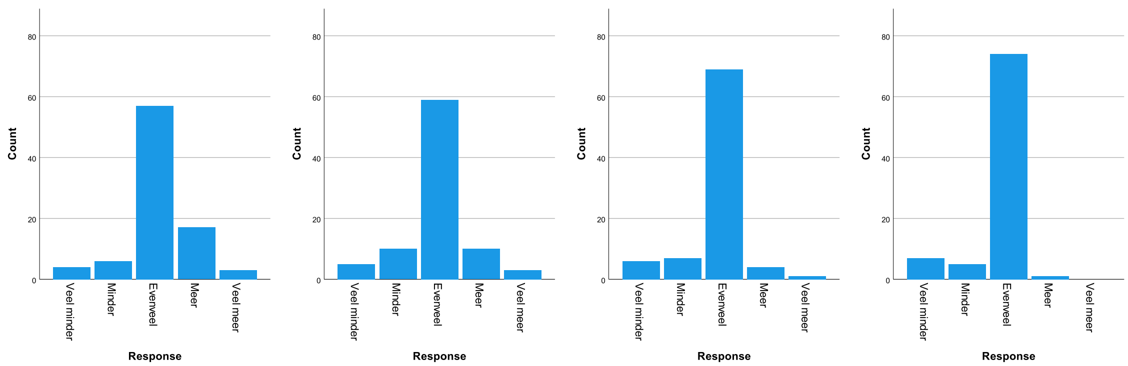

(a) Item a (b) Item b (c) Item c (d) Item d

Figure 9: Results of question 21

22. Hoe gebruikt u digitale hulpmiddelen in de periode van het online onderwijs vergeleken met onderwijs op school?

Table 23: Results of question 22

| Item | Median | Mean | STD |
|---|---|---|---|
| (a) Bij het klassikaal uitleggen van de stof. | 3 | 3.10 | 0.763 |
| (b) Bij het behandelen van opgaven. | 3 | 2.95 | 0.776 |
| (c) Bij het maken van de opgaven door leerlingen. | 3 | 2.85 | 0.656 |
| (d) Bij het maken van toetsen. | 3 | 2.79 | 0.593 |




(a) Item a (b) Item b (c) Item c (d) Item d

Figure 10: Results of question 22

## Appendix C: Interview questions

I. *Gebruik GR en diep leren:*

1. Wat is een typisch voorbeeld van hoe u de GR gebruikt?
2. Hoe denkt u dat de GR kan worden gebruikt om leerlingen te helpen beter wiskunde te leren?
   - m.b.t. Five Strands
   - Wat doet u zelf?
   - Wat doet de lesmethode hiermee?
3. Uit onderzoek blijkt dat de GR een positieve bijdrage levert op het wiskunde onderwijs, hoe denkt u hierover?
   - Operationele en probleemoplossende vaardigheden
   - Houding t.o.v. wiskunde
   - Resultaten leerlingen

II. *Gebruik hulpmiddel en diep leren:*

1. Wat is een typisch voorbeeld van hoe u het hulpmiddel gebruikt? /
   Waarom gebruikt u geen andere hulpmiddelen dan de GR?
2. Hoe denkt u dat het hulpmiddel kan worden gebruikt om leerlingen te helpen beter wiskunde te leren?
   - m.b.t. Five Strands
   - Wat doet u zelf?
3. Uit onderzoek blijkt dat digitale hulpmiddelen een positieve bijdrage leveren op het wiskunde onderwijs, hoe denkt u hierover?
   - Houding t.o.v. wiskunde
   - Resultaten leerlingen

III. *Curriculum:*

Wat vindt u van het huidige curriculum waarin de GR wel wordt toegestaan en hulpmiddelen niet?

- Bent u op de hoogte van de aankomende curriculumwijziging?
- Bent u tevreden?
- Wat zou u verbeteren?
- Zou u de GR gebruiken als dit niet verplicht was?

IV-I. *Toekomst GR*

Hoe ziet u de toekomst van de GR voor u over 5 jaar en over 10 jaar?

- Hoe wilt u dat het wordt?
- Hoe verwacht u dat het wordt?
- Zou u iets ingrijpend willen veranderen?
- Aantal functies GR

IV-II. *Toekomst hulpmiddel*

Hoe ziet u de toekomst van de digitale hulpmiddelen voor u over 5 en 10 jaar?

- Hoe wilt u dat het wordt?
- Hoe verwacht u dat het wordt?
- Zou u iets ingrijpend willen veranderen?
- Zou het hulpmiddel de GR kunnen vervangen?