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The role of dynamic elements in digital teaching platforms - an investigation of students' reading behaviour

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The use of digital teaching materials in mathematics education has gained ground since the first introductions of various hard- and software. A distinguishing feature for digital teaching materials is the possibility to offer interactive and dynamic elements. In this study, eye-tracking is used to explore students' reading behaviour when working with mathematics items in a digital environment. In particular, the focus is laid on how students read depending on the extent to which the items offer dynamic elements. Analysis of data from the eye-tracking in combination with students' responses in the interviews provide a broad picture of different types of challenges that students may face in working with dynamic elements. The results also reveal that commonly used dynamic elements as films or feedback on given answers are valuable because users emphasize them as useful and informative.

Keywords: Mathematics, eye tracking, feedback, stimulated recall.

Introduction

New ways to visualise and opportunities to interact with mathematics provide learning opportunities that have proven valuable, for example in digital books that incorporate dynamic geometry applets (Radović et al., 2020) and in tasks with the ability to give feedback (Stevenson, 2017). In this study we use eye tracking to analyse students' reading behaviour when working with mathematics items with five types of dynamic functions. Increased knowledge about what dynamic functions means for a student working with mathematics is valuable in relation to not only digital teaching platforms, but also other types of digital teaching materials.

Background

Dynamic functions in digital teaching material provide opportunities for learning not possible when printed materials are used. For example, Pohl and Schacht (2019) stresses the need for further research about new digital textbook elements. They contribute an empirical study of student use of textbook elements for the learning of mathematics, highlighting that these elements provoke new types of activities indicating that mathematical hypotheses may also be generated in new ways. In the contemporary rush to digitize there is also a need for awareness of potential shortcomings of digital materials. For example, writing mathematical equations may be harder than on paper and there is a risk of extended use of multiple-choice questions, something that can limit the readers opportunities to actively construct their understanding. Analyses of students' interaction with digital teaching materials have revealed that digital materials contribute in determining how students engage in problem solving by reinforcing iterative strategies such as trial and error behaviours (Lantz-Andersson et al., 2009). Such strategies may impede learning if used instead of problem solving based on analyses of the task, which means that the manner in which students interact with digital materials

is important. Digital teaching materials are for example argued for based on an intention to let students experience dynamic functions and to benefit from automatic feedback from the material. The possibilities to interact with dynamic media, enables an enhanced expressivity and the possibility that the technology functions as a collaborator rather than merely a tool or mediator, which means the mathematical activities become more participatory (Moreno-Armella et al., 2008). The expanded space of interaction in digital resources in contrast to printed (Pepin et al., 2017) implies a potential to play an important role in students' learning. Research also reveals increased learning when digital materials are used to achieve knowledge acquisition through active learning, for example in an interactive response system (Wang, 2020) or using a computerized training method to learn mathematics (Taleb & Hassanzadeh, 2015). An investigation of the effect of various types of feedback offered in digital textbooks revealed a low effectivity of the feedback regarding whether a correct solution was given after receiving the feedback (Rezat, 2019). The feedback did not lead to the desired results even if it was given stepwise in relation to further trials, and the author suggests further development of feedback in digital textbooks.

These previous studies give rise to the question about how students experience work with dynamic mathematics items and receive different types of feedback. In this study we make a contribution by using eye tracking to investigate students' encounters with digital items offering different types of feedback.

Eye tracking, theory and practice

A fundamental assumption when using eye tracking methodology is the eye-mind hypothesis; what you pay attention to and think about is associated with where you place your gaze (see Hoffman, 1998). This assumption has been questioned, and results also reveal that the gaze and the attentional focus sometimes diverge (Schindler et al., 2016). There are however convincing results about the correlation between the gaze and thought (Andrá et al., 2015). What is possible to measure is the students' gaze and how much, how often and for how long the gaze lingers on different elements in the text. Because a prerequisite for decoding and comprehension, the two components of reading according to Gough and Tunmer (1986), is to place the gaze on the text, the data is considered to reflect parts of the reading process. Based on the eye-mind hypothesis, the gaze is here interpreted as reading the multimodal and dynamic text elements in the analysed items.

In mathematics education research, eye tracking has proved to be particularly beneficial for studying processes, not outcome, and for research including aspects of visualisation and mental representation (Strohmaier et al., 2020) and because these descriptions hold for the current study the method choice is reasonable. The current study takes its starting point from a previous study revealing a limited use of dynamic and interactive elements in digital teaching platforms in mathematics (Dyrvold, submitted) which raised a question whether such elements should be used more. In the current study, eye tracking enables a comparison of reading behaviour depending on the offered dynamic and interactivity in mathematics items. Heat maps (visualising fixations) offers snapshots of students' reading that are easy to interpret, and therefore valuable in stimulated recall interviews.

Aim

The aim of the study is to achieve an in-depth understanding of reading behaviour in a digital multi-modal environment: teaching platforms in mathematics. To enable analyses of which role variations in interactivity and dynamics plays for reading behaviour, mathematics items with elements that differ in those aspects were designed. These different element types are described in the Method section. Two research questions are posed; i) what do different element types mean for how a text is read?, and ii) how do students experience reading digital materials with different element types?.

Method

Three grade nine students (15 years old) with much gaming experience have participated in this study. The students were selected using a convenience sampling and were familiar with the interviewer. The students' previous mathematical achievements were unknown. Each student worked with five items in a digital environment, each containing one mathematics task, and their work was monitored using eye-tracking equipment. The items were designed to touch on areas of mathematics that are new to the students. The apt difficulty of the items was outlined based on a review of Swedish grade nine textbooks. At a later stage tentative items were further discussed and adjusted in cooperation with two teachers who are also experienced textbooks authors. All items had the same structure, consisting of three parts, an introductory text, a question and some essential theoretical content (hereafter called Theory), each part constituting an area of interest (AOI). The eye-tracking analysis was built on how the student's gaze moved between these AOIs (visualised as the four grey areas in Figure 1).

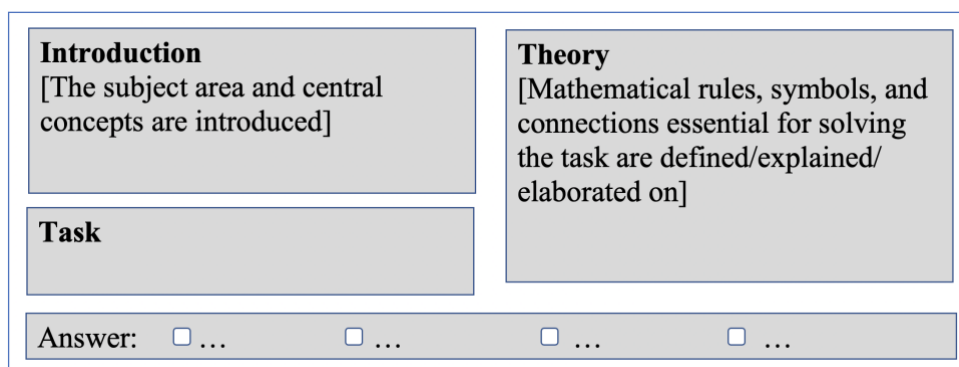


Figure 1: Basic design of the items and visualization of areas of interest (AOIs)

The intention was that the task should not be able to solve based only on the introduction; rather the Theory would be needed. The Theory is essential in the analysis because the type of elements (i.e. how dynamic and interactive) utilized in this section is altered between the items. With access to the information in the Theory, the intention was that the tasks could be solved without using paper and pencil. The Theory in each item was designed with a dynamic function, from one of five element types (ET) (Dyrvold, submitted). The element types with their characteristics are as follows: ET1, static presence: static content, e.g. similar to typed text in print; ET2, opted presence: static content opened by a click, e.g. a definition; ET3, dynamic presence: continuously dynamic but not interactive, e.g. film; ET4, dynamic feedback: dynamic and (instantly) interactive, e.g. to choose in a list and receive feedback; ET5, continuous dynamic feedback: continuously dynamic and interactive, e.g. by providing feedback when dragging.

The students were interviewed with stimulated recall directly after working with the items following a semi structured and pre-formulated interview guide, based on three main themes. The first theme took its point of departure in the question “What did you think about the items in general?” in order to capture the students’ general impression of the items and the various dynamic functions. The second theme concerned the question “Is there anything special that you thought of when you worked with the different types of Theory?” (Interviewer exemplifies if needed). After that, heat maps from the students’ work were shown to the students (visualizing main fixation points) and they were asked questions on their reading of the items and the five element types for example: “How did you think when you worked with this item”, “You looked at X for a long time/several times, do you remember how you thought or why you looked at just that?”, “When you see how you read the Theory, do you remember anything special?”, and finally “What are your thoughts about the various dynamic functions in the items?”. The interview leader was well known to the students, the interviews were recorded and transcribed verbatim, and then summarized using short notes. Analysing these two kinds of data together contribute to fulfil the aim of the study because the different data nuance and enrich each other.

Eye tracking analysis

The students’ readings were analysed based on the following analysis questions: (1) How appealing do the students perceive the different element types? (TFF – time to first fixation on the ET); (2) How do the students use the different element types? (Fixation duration (FD) on ET and total number of fixations (TNF) on the ET); (3) How do the students read the explanations in the Theory due to element types? (Fixation duration on introduction and on task in relation to ET ((I+T)/ET)

Time data from the eye tracking and short notes from the interviews with each of the three students were compiled and qualitatively analysed to gain insight into the relation between reading behaviour and experience of reading the text. The current study is to be followed by a larger quantitative study and results in relation to the current study will also be used to refine the method in the larger study.

Result

The results reveal both differences and similarities in how students perceive and read mathematics offered using different element types. There are not very distinct differences between how students interact with the five element types but if the element types are clustered according to level of interactivity and dynamics, some patterns occur. The results reveal both differences and similarities in how students perceive and read mathematics offered using different element types. There are not very distinct differences between how students interact with the five element types but if the element types are clustered according to level of interactivity and dynamics, some patterns occur.

Table 1: Overview of collected data about the element types for each participant

	Item 1:ET1			Item 2:ET 2			Item 3:ET 3			Item 4:ET 4			Item 5:ET 5		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
TFF: ET	0.6	1.6	0.3	89.6	0.1	37.8	1.2	1	6.4	11.3	21.1	19	20.1	20.7	4.3
TNF: ET	29	52	59	107	81	69	158	205	122	49	56	31	145	100	156
AFD: ET	8.1	21.7	19	33.3	29.5	19.64	63.5	91.2	47.7	22.2	29.3	10.5	66.5	50.6	61.1
AFD: I	34	13.6	20.3	48.7	26.9	34.1	8.7	20.7	12.7	15	19.7	15.6	10.7	11.1	8.5

AFD: T	7.7	7.9	8.6	33.3	47.5	22	37.5	44.1	57.1	54.7	124.8	32.5	23	20	14.1
[AFD]: (I+T)/ET	5.17	0.99	1.52	2.46	2.52	2.85	0.73	0.71	1.46	3.14	4.94	4.56	0.51	0.61	0.37

Measures are given in seconds except TNF, which is given in number of counts

Results in relation to the two research questions about how the items are read and how students experience the reading are presented in themes, where each theme relates to both research questions.

Theme 1. There is a pronounced difference in how the students read an item with only static content (ET1) in contrast to items with dynamic and interactive content (ET2-5).

Less fixations and less time is spent on the Theory that is purely static. One student (S1) refers to the heat maps with ET1 saying “I read it [Theory] several times” and “The concepts were difficult and therefore I looked at the image [introduction] several times” indicating an experience of having engaged deeply with the text. Eye tracking data reveal that items with ET2-5 do generally reveal more fixations and totally longer summarized fixation time on the AOIs. The students’ experience from reading these items and reflections on the heat maps reveal several explanations to this pattern. Most prominent is utterances about joy and usefulness: “I liked the opportunity to drag” (S2) (see Figure 2), ”I thought it [receiving feedback] was good ... because it shows that you understand” (S3).

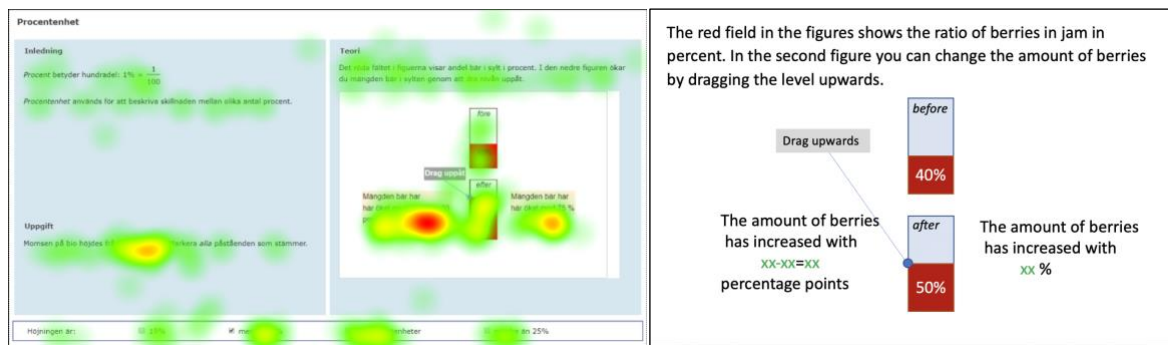


Figure 2: Heat map showing S2 dragging in ET5 and translated Theory part.

In the dynamic element (Figure 2) the green values on both sides on the rectangle changes dynamically when the level is dragged upwards. The translation of the introduction and task reads as follows: Per cent means hundredth $1\% = 1/100$. Percentage points is used to describe differences between different numbers of per centage. Task: The VAT on cinema tickets increased from 6% to 25%. Tick all correct alternatives (19%; more than 50%; 19 percentage points; less than 25%).

Theme 2. Dynamic elements have a potential to evoke deep engagement in interaction, but there is also a risk of misunderstandings or omission in relation to the elements.

The eye tracking data reveal that the students fixate their gaze on Theory as a static page (ET1) or film (ET3) immediately (almost in every case within two seconds). In the Swedish context, these element types are something the students are familiar with. In the item with ET2, on the other hand, one student (S1) left the Theory unread for quite a time because the student did not realize that more content was offered behind a click. Another student (S2) referred to the same content as clearly presented and “fun” to be able to open. In the item with ET5 the invitation to interact with the material

is by one student perceived as part of the task to solve, not Theory, “Because it was possible to drag, it made me think that it was part of the task” (S1), something that made the student a bit confused.

Theme 3. Some element types demand investment in time from the reader, but time spent on the element does not assure that the reader is engaged in a learning situation.

The eye-tracking data do rather clearly show that the students engage the most with the Theory presented as a film (ET3) or a continuously dynamic activity (ET5). If the reader does what is requested these elements have an inherent demand of persistence. A film may not make sense if not watched to the end, and a dynamic activity may leave questions lingering if not completed. In this study the participants invested the required time, and when that is the case, the content offered has a large potential to provide a fruitful learning situation. On the other hand, if for example a film is omitted, this learning situation is lost. The student with most fixations on the film (S2) watched the film twice and explained clearly the benefits with a film “It is easier to understand when someone is reading. Then you get help with symbols that are read”.

In addition to these results there were some differences between the participants’ reading and reflections about the items that call for attention because they highlight that there is no such thing as the best teaching material. The usefulness is to a large extent dependent on who the reader is and if a sound base material is offered, it provides a good fundament for a learning situation. The teacher is essential and discussions and other activities can contribute further to the individual use of digital teaching platforms. For example, one student (S3) explains that he missed the information “drag” when he read the item with ET5. He experienced the item as too difficult and did mainly struggle to get a grip on what was requested in the item. In this particular case, a discussion with a peer or a teacher could have clarified the intention with the item.

Discussion

This study is designed as a response to the current development of digital teaching materials. The current study contributes to this issue with insights about how dynamic and interactive elements can be used to boost students’ gain from interaction with digital materials. The results highlight students’ engagement with items that are dynamic and interactive but also some potential challenges. The analysis reveals both enthusiasm and engagement in the dynamic ETs, also for a minor addition of questions which return ‘correct/false’ directly, in the Theory (ET4). The positive result in relation to ET4 was not expected, since it is such a trivial addition to a static text. However, the same element type caused some quandaries because the questions signal to the students that this is the task to solve, not a part of an explanation.

Previous studies highlight that what students choose to engage with and how, in digital materials, is a factor worth taking into account when evaluating such materials (Lantz-Andersson et al., 2009; Bartelet et al., 2016), and the attraction to element types that offer interaction is notably on this issue. The students in the current study invested in the dynamic element types, also when the student “didn’t understand anything”, and such engagement must enhance the chance of learning. The persistence with which the students engaged with ET3 and ET5 was also surprising. The participating students are used to rapid activities in a digital milieu, which may cause restlessness, something that did not seem to affect the reading negatively. A lingering hypothesis is that previous rich digital experience

may have fostered an ability to skim and to use split vision in a fruitful way. Such an ability could explain that students with many fixations and a high fixation duration on the ET also had high values for the AOI on introduction and on the task. The question remains to investigate further.

In this study the combination of eye tracking data and students' reflections on their reading behaviour constitute rich data useful for in-depth analyses. The number of quantitative measures may falsely signal an intention to generalise about relations between reading behaviour and particular element types, which is not our aim. These measures are, in the current study, meaningful in relation to the interview data, because reading behaviour differs between readers and also depending on the intention with the reading. It is also important to be aware of the difference between the five items, both regarding representations and mathematical complexity. This means the reading experience may differ more regarding other aspects than the ETs between the items, and accordingly comparisons between the reading of ET1-5 must here be done very carefully. A limitation in the current study is also that the items are designed to suit the set up with quantitative analyses using eye tracking equipment and therefore the dynamics and interactivity is only found in the Theory.

Visualisations such as heat maps are often criticised for being just 'eye candy' but when used to replace read aloud protocols this kind of data is very useful because it aids the students in recalling their solution process. The interviewed students were, aided by the heat maps, able to give rich descriptions of how they experienced the items depending on element type in the Theory. A refinement of the interview guide will however be made in relation to the heat maps because the students were very prone to describe what they saw, not their thoughts when they read or reasons behind the reading pattern. The results are applicable not only in relation to digital teaching platforms but for all types of digital teaching materials in relation to the extent they incorporate dynamic and interactive elements and functions.

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