AFFORDANCES AND CONSTRAINTS OF THE E-ASSESSMENT SYSTEM NUMBAS: A CASE STUDY IN MATHEMATICS TEACHER EDUCATION

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ABSTRACT

E-assessment systems such as Numbas are now widespread in mathematics education at the primary, secondary, and tertiary level. However, little is known about the affordances and constraints of Numbas in mathematics teacher education. The purpose of this study is to investigate the emergence, perception, and actualisation of Numbas affordances and constraints, and their effect on teaching and learning mathematics. The study draws on Gibson's affordance theory and associated research in the field of digital technology. It follows a qualitative research design to generate data using semi-structured interviews of six students and two teachers. Data from the interviews were analysed thematically to highlight the affordances and constraints of Numbas and their effect on mathematical learning and teaching. Future work will continue exploring Numbas affordances and constraints for learning and teaching mathematics in similar educational settings to ensure more validity and reliability of the results.

KEYWORDS

Affordance, e-Assessment System, Constraint, Feedback, Formative Assessment, Numbas

1. INTRODUCTION

In recent years, emergent technologies like e-assessment systems are gaining more attention in mathematics education, partly, due to the high number of students' enrolment that has necessitated the use of technological tools for feedback delivery to students for mathematical learning.

E-assessment systems provide a resource-efficient way to providing the much-needed timely feedback to the students. As such, these systems provide new learning potentials for a large cohort of students by means of formative assessment. However, research on e-assessment systems is still in its infancy, especially in the area that assesses the affordances and constraints of such systems. Csapó et al. (2012) posited that large-scale implementations of technology-based assessment still need further research and experiments in real educational settings.

The present study proposes a framework that captures the affordances and constraints of Numbas in a technology-based course in teacher education at the Department of Mathematical Sciences, University of Agder. The goal of the study is to investigate the emergence, perception, and actualisation of Numbas affordances and constraints, and their effect on teaching and learning mathematics. The study follows a qualitative research design in which data were generated using semi-structured interviews. Eight interviews were conducted to collect the views of six students and two teachers. To address the research goal, the interview data were analysed thematically using an inductive-deductive approach.

The paper is structured as follows. Firstly, results from previous studies on feedback and e-assessment systems are presented. Secondly, an overview of Numbas is given. This is followed by the framework of the study drawing on Gibson's affordance theory. Then, the data collection and analysis methods are presented, and the results are outlined. Finally, a discussion and implications of the results conclude the article.

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2. E-ASSESSMENT SYSTEMS: A LITERATUR REVIEW

Feedback is an integral part of learning processes. It plays an important role in development new instructions and amendment of existing ones to meet special needs of students. It is adjudged to be one of the most powerful ways to increase students learning and achievement (Hattie & Clarke, 2018). Hattie and Timperley (2007) defined feedback as the information provided by an agent, which may be the teacher, parents, fellow students, books, or even experience about the performance of oneself. Butler and Winne (1995), and Goldin, et al. (2017) in agreement with the definition proposed by Hattie and Timperley (2007), asserted that feedback does not necessarily come from agents external to the learner but can be generated internally by the learner herself.

While feedback has been aligned traditionally as information provided by external agents (teachers, parents/guardian, fellow students) or the learner herself, Goldin et al. (2017) argued that through information and communication technology, a broad range of feedbacks are also provided to the learner. This could be in form of e-assessment systems, or other digital learning environments. With the aid of feedback, learners can confirm or alter their knowledge and skills, which may lead to improved skill acquisition, better learning process, and learning outcomes (Attali & van der Kleij, 2017; Shute, 2008).

Formative feedback is considered to be any form of information made available to students regarding their actual state of performance with the aim to modify their thinking or behaviour towards achieving the set learning goals (Goldin et al., 2017; Shute, 2008). Irons (2007) further suggests that such information accelerates learning, either by "enabling students to achieve higher learning outcomes than they might otherwise have attained, or by enabling them to attain these outcomes more rapidly" (p.21). Formative feedback gives the students the opportunity to access the level they are in a learning process, what the learning goals are, and how to achieve them.

In the last decade, several studies have reported about an increase on the uptake of e-assessment systems in schools (Denton, Madden, Roberts, & Rowe, 2008; McKenna & Bull, 2000; Özden, 2005; Thelwall, 2000) mainly due to the increase in number of students enrolling for science, technology, engineering, and mathematics (STEM) courses (Gill & Greenhow, 2008; Jones, 2008).

Hettiarachchi et al. (2014) in their study found significant improvement in performance and participation of students who engaged in learning with a formative e-assessment system, Technology-Enhanced Assessment (TEA). Berková (2016, 2017) studied the efficiency of teaching undergraduate calculus course using an e-assessment system called Maple T.A (Testing and Assessment), in the report, he found the result to be significantly higher when the students learn with the aid of the system than when they learn with the traditional method of doing homework with paper and pencil.

There exit few reports on the implementation of the e-assessment Numbas in teacher education (Hadjerrouit 2020b). In school education, the use of Numbas shows positive improvements of students' performance. For example, Carroll et al. (2017) showed in their study with the first year Business studies students that attendance was higher with about 20% in the classroom that used Numbas for formative assessment. They also reported that the students found Numbas feedbacks helpful, and their enjoyment of learning mathematics increased.

3. THE E-ASSESSMENT SYSTEM NUMBAS

Numbas is a general e-assessment system for mathematics and mathematics-related courses with emphasis on formative assessment and feedback to students' actions (Lawson-Perfect, 2015). From a didactical point of view, the primary use of Numbas is to enable students to enter a mathematical answer in the form of an algebraic expression, and then see how a particular characteristic of affordances, the one of feedback can impact students' mathematical engagement. Numbas makes its feedback immediate and potentially effective. There are multiple ways Numbas gives feedback to both students and teachers. These include *submit answer, show steps, reveal answers, try another question like this one* (Figure 1).

Submit answer: Students get feedback when they submit an answer. The feedback indicates with a green colour 'good' sign if the answer is correct, with red colour 'bad' sign indicating that the answer is wrong or partially correct. The students will be shown the maximum attainable score for each question, and their own score for the question after they have submitted the answer. The teacher may choose to disable these feedback options.

Show steps: When "*show steps*" is chosen, Numbas will give the general solution to that task. This is a way of reminding the student to have a look at the general solution and retry solving the task. Show steps does not give students the exact solution to the particular task.

Try another question like this one: With this option, students have the opportunity to attempt similar questions many times until they feel confidence to move to the next question.

Reveal answer: This option provides a step-by-step solution that is personalized to the question, but the students lose all the marks and cannot re-attempt the exact question. The teacher may decide to disable this.

Statistics: Numbas stores data of students' performance. Teachers can track how well the students understand the topic through their performances, and they can equally identify the tasks students perform below expectations and reemphasize on them in the next class.

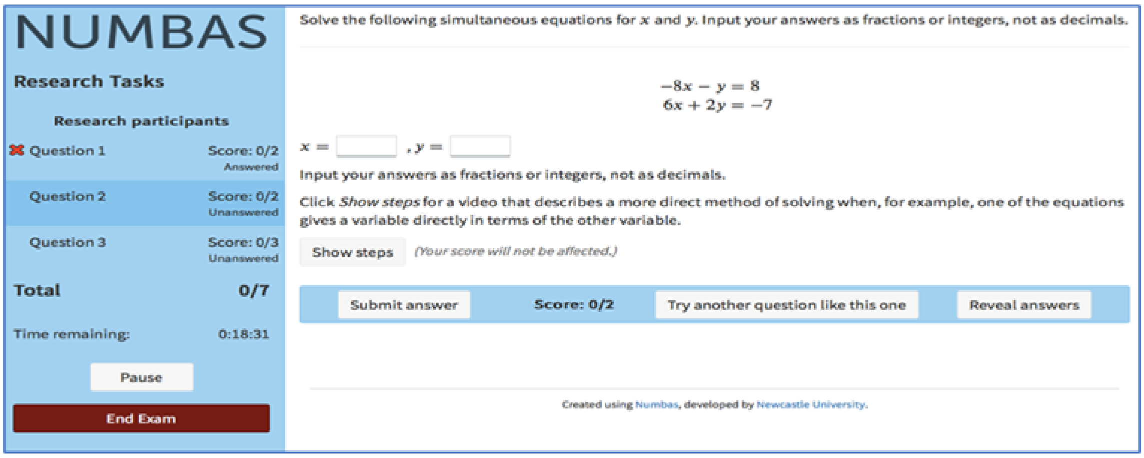

Figure 1. Numbas feedback options

4. ANALYTICAL FRAMEWORK: AFFORDANCE THEORY

This study uses affordance theory as an analytical framework for operationalizing Numbas feedback. In addition to the study on Numbas mentioned in the previous section, this theory was used to explore affordances of the digital tool SimReal for learning mathematics in teacher education (Hadjerrouit, 2020a).

The term 'affordance' was proposed by James J. Gibson (Gibson, 1986, p. 127) to describe what the environment offers the animal. He argued that affordances (henceforth, in plural or singular form) can be seen from the properties of the environment that are relative to the animal in question. He further stresses that affordances must be peculiar to the animal they afford; not just any property of the environment or whatever the environment can offer.

In the world of Human-Computer Interaction, the term "affordance" (Norman, 1988) refers to a goal-oriented action potential that emerges as result of interaction between subjects (e.g., students and teachers) and an object (e.g., Numbas). Affordance is neither the property of an object in isolation nor that of the subject. Instead, it emerges as an offshoot of a dynamic relationship between the subjects (students and teachers) and the object (Numbas). It is perceived (i.e., students and teachers are aware of the existence of the action potential of Numbas) in many ways and actualized (i.e., students are able to turn the potential of Numbas into action) to produce effect (i.e., feedback delivery) depending on many factors that include Numbas platform, its user interface, capability of the students and their level of preparedness. Moreover, the actualization of Numbas affordance is either facilitated by some enabling conditions or mitigated by some constraints.

Given the emergence of Numbas affordances, it is important to ask how the affordances are perceived. As such, when students interact with Numbas to facilitate feedback delivery on some mathematics concepts they do so conveniently with the aid of the technical features of the tool. During this process, they become aware of the affordances that emerged during the interaction in terms of feedback delivery. The next issue is how they can actualize these affordances. Affordance actualization is a process of turning action potentials (affordances) into real actions to bring an effect in using a particular tool (Anderson & Robey, 2017; Bernhard et al., 2013).

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To turn a possibility into an action, it is expected that the user has the ability and capability to harness the potential and there are enabling conditions to facilitate the process. Affordance actualization may vary from one individual to another because it is goal-oriented and a process of specificity. Two or more students may interact with Numbas and actualize (or not) different affordances of the tool depending on their respective individual differences and choices.

Moreover, it is expected that following the actualization of Numbas affordances are some effects, which may be "intended by the user and/or those by the original creator of the artefact as well as unintended effects" (Bernhard et al., 2013, p.6). Thus, it is expected that when affordances are perceived and actualized, then some effects are generated in terms of feedback delivery on mathematics tasks to students. Figure 2 shows the underlying framework that captures the emergence, perception, actualization, and effect of Numbas affordance.

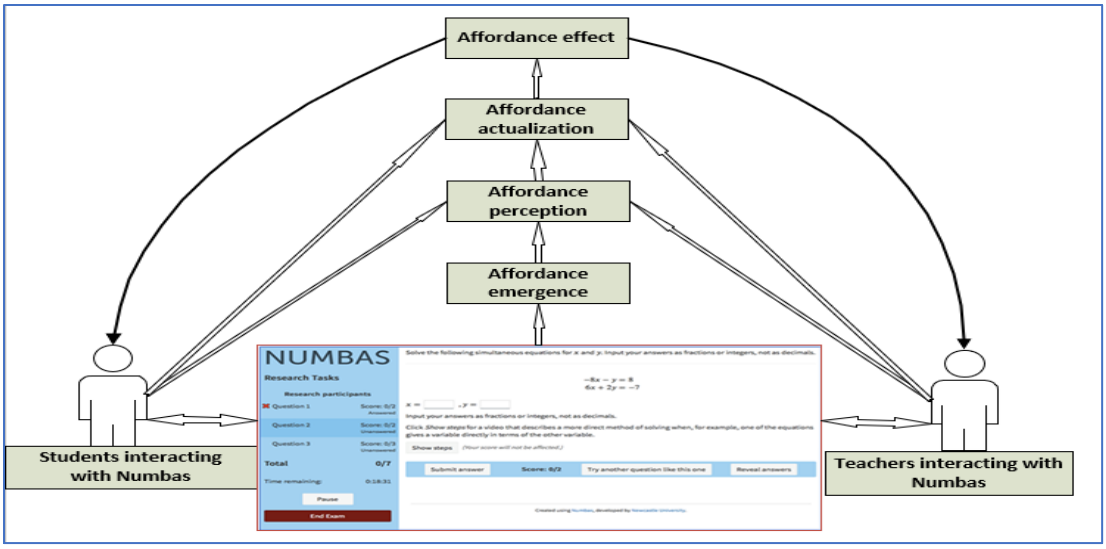

Figure 2. Framework that captures the emergence, perception, and actualisation of Numbas affordances, and their effect from an Activity theorical perspective

The perception of Numbas affordances concerns its awareness by a goal-oriented user during the interaction. Affordance actualisation is a process of turning action potentials (affordances) into real actions to bring an effect in using a particular tool (Anderson & Robey, 2017; Bernhard et al., 2013). In specific terms, affordance actualisations are "the actions taken by actors as they take advantage of one or more affordances through their use of the technology to achieve immediate concrete outcomes in support of organizational goals" (Strong et al., 2014, p. 70).

Moreover, it is expected that following the actualisation of Numbas affordances are some effects. More so, it is important to highlight that actualisation of Numbas affordances does not happen in isolation. In fact, affordances go along constraints; they are facilitated by enabling conditions and hindered by constraints. As captioned by Hadjerrouit (2020a, b) affordances and constraints are inseparable because they complement each other, and not opposite. The mechanisms of actualisation of Numbas affordances coupled with the constraints and their actualisation appear not to have been reported in the literature.

5. DATA COLLECTION AND ANALYSIS METHODS

A case study design approach is used to analyse the affordances perceived by both students and teachers while interacting with Numbas, and how they actualize the perceived affordances. The participants were two teachers and six students from a mathematics teacher education class of a Norwegian university. The two teachers were considered because they are actively making use of Numbas for formative assessment in their respective classes. The second cohort is six out of about twelve students from one class who willingly volunteered to participate in the study. These participants are master's degree students from an institute of mathematical sciences in a Norwegian university. They were currently taking a course entitled "Digital tools in mathematics teaching". Both cohorts were familiar with Numbas and affordance theory. The present study is a continuation of previous studies (Hadjerrouit & Nnagbo, 2021; Nnagbo, 2020).

A thematic approach to data analysis was used to identify codes within the data set (Bryman, 2016). Code development takes a deductive-inductive strategy. The analysis starts with a deductive approach by following the pre-defined framework in search for meaningful interpretation of the data. Then as the process evolves, room was given for the data to express itself by creating new codes that emerged from the data inductively. The development of codes follows reading and rereading of the data carefully and annotating same to identify topics raised by participants themselves. The codes are refined and validated by checking whether these are repeated or highlighted by the participants as important themes (Hennink et al., 2020).

6. RESULTS

The results are divided into two parts: Students' and teachers' views on Numbas feedback and affordances that emerged between the participants and Numbas. The results also report on the similarities and differences between students' and teachers' views. In addition, the theme 'diagnostic teaching' emerged from the empirical data during code development.

6.1 Students' Views on Numbas Feedback

The results reveal that feedback options are available on the Numbas user interface, and that the students perceived these feedbacks. The feedbacks are in form of immediate interpretation of the students answer inputs for them to see how Numbas understand and read their answers, as well as the immediate response of 'correct' or 'wrong' that comes in form of green or red mark respectively they receive from Numbas when they submit the answers. Other feedback mechanisms of Numbas like "hint", "reveal answer", "try another related question" "submit answer" are shown to be available and from the result, the students seem to find them very helpful.

For example, when asked about the Numbas feedback(s) while doing the tasks that were given to them, one of the students responded: "…*with the two equations, there was a movie, and it was sort of helping because it assured me that I was doing it in the right way*. Another participant indicated that "*it was helping because it was the rule you were supposed to use*". Likewise, another student explained that "*it gives you a lot better feedback, than most of that kind of programs…So that feedback is good, and as I said, when you write, the next box shows you how the program interprets, that program is really good*".

From the students' responses, they seem to appreciate the feedbacks, including the video hints. The response from one student does not only show that the video helped her, it also encouraged and motivated her to solve the task. Her confidence increased. Another student tried comparing the feedbacks to that of other similar programs and she found it better than other programs she had used. She was particularly overwhelmed that Numbas could instantly show how it understands her answers.

Some of the responses given by the students further show that they are not just aware of all the other feedback options, but they also actualized them while interacting with Numbas, and the feedbacks really helped them. For example, when the participants were asked if they were stuck while attempting the tasks, and if yes, how do they overcame it, one of the students said "*yes, I was stuck. First, I tried to use the 'show steps' and also 'show result…"*. Another student replied *"yes. I have written my maximum point to the minimum, and the minimum point to maximum, I found them, but I wrote them wrong, and I solved it again, and I found the same coordinate, … I solved it three times, I found the same coordinate, I just couldn't see that I wrote them wrong though I was able to see it later when I revealed the answer*…". From the submissions, the students were stuck at one point or the other while solving the interview tasks, and they sought and got help through the different feedbacks in Numbas. The first response shows that the student explored two feedback options in order to get unstuck. The second response on the other hand shows that the student was left frustrated by her own mathematical mistakes. She had already spent some time and effort trying to trace her fault but to no avail. From every indication, she could have abandoned the task, if not for the feedback from Numbas which helped her get unstuck.

Furthermore, the result revealed that all the students interviewed perceived the feedbacks they received as helpful, and they expressed their satisfaction with the feedbacks. This is substantiated from their responses.

One student pointed out: "*yes! the hints were highly helpful to me*…". Another student replied "… *I was happy that it helped me to remember the formula …it's a good feeling when you use the digital tool and you are stuck, and it can help you solve it because then you are learning as you are doing exercises*…"

6.2 Teachers' Views on Numbas Feedback

From the teachers' perspective, the findings show that their students equally found Numbas feedback helpful and motivating. They state that their students "do get stuck" and when they do, that "most of them chose to show hints and the tips, (and) the other feedback options from the program". They also think that the feedback motivate the students. However, they believe that bulk of the work lies on the teachers' ability to create tasks that would take into consideration the students' likely misconceptions about a particular task.

They further expressed concerns that the feedback, no matter how good it may be, may never be sufficient to get some students going, especially the low achieving students. This can be deduced from the response offered by one of the teachers "*I would say that the feedback does help them but again, …, for the strongest students, it's helpful for them but the weaker students, I think they need the teacher actually to tell them what have you done wrong, it's not enough for them to see the feedback or the examples*."

6.3 Similarities and Differences between Students and Teachers' Views

Generally, the participants, both teachers and students, think that the feedback mechanisms in Numbas are good and helpful. They seem to appreciate that the feedback options show the general rules or formula for solving a particular task without going into details about the actual solution to that task.

It appears that the students perceived and actualized some affordances of Numbas at the assessment level especially the availability and usefulness of feedbacks. They seem to appreciate that Numbas shows them how it reads their inputs as soon as they are typing them. The students further expressed their satisfaction that the feedback could help them get unstuck. However, teachers' inability to take full advantage of the potentialities of Numbas while designing tasks and its corresponding feedbacks could be seen as constraints towards complete actualization of Numbas affordances at the assessment level. They also feel that the feedback would be better if Numbas could provide step by step feedback to students, by taking their profiles into account. Teachers also testify that the students are satisfied with the feedback mechanisms.

6.4 Diagnostic Teaching

The theme 'diagnostic teaching' emerged from the data during code development. Its emergence is due to repeated expressions regarding the possibilities of teachers to use Numbas to ascertain the students' areas of difficulties before meeting them in class. The findings reveal that Numbas can be used as a powerful tool to implement diagnostic teaching to either a single or large number of students.

The teachers expressed that Numbas provides statistics in form of performances of their students. The statistics shows both the time the students spent on each task, if they reveal hints, the algebraic expressions they type in as their answers, and so much more. From the teachers' responses, it can be deduced that they found the statistics helpful in many ways, especially in diagnosing the students' learning difficulties, and time saving.

One of the teachers came up with the following comment: "*I can go in as the teacher and see what they have answered, I can see if they have revealed hints, so gives me a lot information, I can see how much time they have spent on the question, of course, if it is correct or not, so I will see their answers, I mean the algebraic expressions they have typed in, for each student. So I can compare and see, if I want to I can break it down to each student or I can give the percentage of how many students (), you can an overview of the whole class, you see the average time they spent on each question, so I will know that in this question they used a lot of time and they didn't get it correctly, then I know, then ok I know this is something we have to work on in the next class, so that is very useful information for me as a teacher*…"

The other teacher further indicated that "*the statistics is useful in itself for me when I apply my teaching because I'd known this task, we need to see more of (.)... This is really useful to the instructor…this is time saving, it's a huge time saver, …*"

On the other hand, students' responses signified that they also see Numbas as a good diagnostic teaching tool. they believe that with the aid of the statistics at the teacher level, they would know beforehand what the students struggle with. One of the students suggests, "*…if you have problem with one (task), we know what your problem is, what you are struggling with. Its already diagnosed for the teacher so h/she knows what h/she must explain more to you*".

7. DISCUSSION AND CONCLUSIONS

The goal of this research study is to investigate Numbas affordances and constraints, and their effect on teaching and learning mathematics. The results show that the students perceived and actualised the affordances of Numbas particularly because of the availability and usefulness of the e-assessment system's feedbacks, which in turn increase the students' motivation. Clearly, effective feedback on assessment is vital to improve learning (Hounsell et al., 2008; Pereira et al., 2016). However, there is a concern that some might not find Numbas feedbacks helpful, because they would always need a teacher to tell them why they got a certain task wrong. This further shows that digital assessment tools may not completely replace teachers.

Regarding implications of the study, it is important to mention that the proposed research has used formative assessment, which has been useful in underpinning the results of activities undertaken by teachers and students for assessing themselves. The findings show that Numbas is a useful tool for assessing mathematical concepts and problem-solving. However, there are issues related to the feedback, which can act as a source of motivation for a few students while demotivating other students. Numbas may be included to the Norwegian course curriculum with the sole intention of identifying possible problems and effecting necessary modifications along with improving the learning of students and teachers.

For teachers, it is important to ascertain their role in using their skills and expertise for adding new strategies of formative assessment, and identifying students' learning progresses, while for students, it is important to focus on using Numbas as a practice, learning, and feedback tool. However, in the educational setting, the role of Numbas should be clearly defined along with the role of teachers. For example, teachers should identify why students need to use the tool when tasks assigned to them on Numbas. Teachers should also identify the role of personal feedback and Numbas general feedback in affecting the student's learning process. For students, it is important to weigh the learning patterns and potential in using teachers' ideas and Numbas explanations. From the university perspective, it is important to analyse whether Numbas is able to facilitate higher order thinking and learning or not. Also, the focus should be on determining the cognitive behaviour and improvement of students. There should be a clear distinction of students on the basis of higher and lower level of cognition. The responsibilities of teachers for improving the learning of students using Numbas should be explained and defined properly. Such implications need to be further integrated for reformulating a new strategy, which will be able to support the formative assessment process.

Summarizing, this study helped to identify some conditions for using Numbas as an e-assessment system in teacher education, and to understand how to take advantage of formative feedback to support the implementation of new educational goals both for students and teachers. However, the low number of participants ($N=8$), that is two teachers and six students, limits how much the results can be generalized. Future work will continue exploring Numbas affordances for learning and teaching mathematics with a larger number of participants to ensure more validity and reliability of the results, and extend these to similar but more advanced e-assessment systems such as STACK (Stack, 2022), and additionally to digital exams in educational settings.

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