ANALYSING AFFORDANCES OF THE E-ASSESSMENT SYSTEM NUMBAS IN MATHEMATICS EDUCATION FROM AN ACTIVITY THEORY PERSPECTIVE

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ABSTRACT

The purpose of this paper is to investigate the affordances of the e-assessment system Numbas from an Activity Theory perspective. The study follows a qualitative research design combined with semi-structured interviews with six students and two teachers. The findings reveal that the students were able to perceive and actualise several affordances of Numbas, such as ease of use and navigation and possession of facility to contain mathematical knowledge. The participants acknowledged that Numbas affords variation in mathematical contents and support for the development of pen and paper skills. Numbas also affords learner's autonomy and motivation to engage in mathematical problem-solving. Findings further show that Numbas promotes formative assessment. This can be seen from the high level of affordance perception and actualisation amongst students and teachers.

KEYWORDS

Activity Theory, Actualization, Affordances, Constraints, E-Assessment, Emergence, Feedback, Perception, Numbas

1. INTRODUCTION

The provision of feedback to students is considered to have a significant influence on learning achievement in mathematics, especially when the feedback is timely, constructive, and oriented towards improvement (Burns, Martin, & Evans, 2019). It can be received from teachers or peers. Feedback is one of the five key strategies in the framework proposed by Black and Wiliam (2009) for formative assessment. As such, it is difficult to disjoint feedback from any form of formative assessment in mathematics education (Kyaruzi, et al., 2019). However, there seems to be a consensus among education researchers that for feedback to be effective in enhancing students' learning outcomes it should be task-specific, contain learning-related information, timely and informative (Einig, 2013; Hattie & Timperley, 2007; Pinger, et al. 2016). Given the need to provide timely feedback to students, several institutions have been responding by experimenting with different ways to address this need (Einig, 2013). Recently, technologies like e-assessment systems are gaining more attention in mathematics education because they provide a resource-efficient way to providing the much-needed timely feedback. E-assessment 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 their affordances and constraints. The present study proposes a framework that captures the affordances of Numbas in a technology-based course in teacher education. It is a continuation of previous studies (Hadjerrouit & Nnagbo, 2022a; Hadjerrouit & Nnagbo, 2022b; Hadjerrouit & Nnagbo, 2021; Nnagbo, 2020). The participants were six students and two teachers. This study addresses three research questions:

1. What affordances of Numbas are perceived by students and teachers?
2. How are the affordances of Numbas actualised by students and teachers?
3. What are the constraints for the actualisation of Numbas' affordances?

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2. NUMBAS

Numbas is a general e-assessment system for mathematics-related courses with emphasis on formative assessment and feedback to students' actions. It has been developed by the e-learning unit of Newcastle university's school of mathematics and statistics (Perfect, 2015). 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 Numbas feedback can impact students' mathematical engagement. Numbas performs marking on the client which makes its feedback immediate. There are multiple ways Numbas gives feedback. These include submit answer, show steps, reveal answers, try another question like this one.

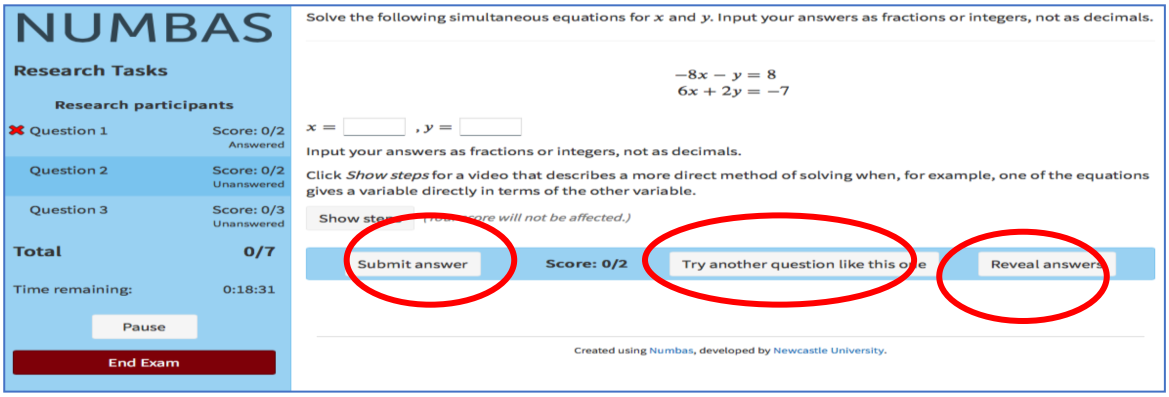

Figure 1. Numbas feedback options

- **Submit answer-** Students get instant feedback as soon as they submit an answer. The feedback simply indicates with a green colour 'good' sign if the submitted answer is correct, with red colour 'bad' sign indicating that the supplied answer is wrong, or partially correct, with feedback message underneath. The students will also 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 a student clicks on the show steps, Numbas gives the general solution to that question. It may include video or graphical explanation depending on the kind of feedback the teacher puts in there. This is a way of reminding the student to have a look at the formula or the general solution and retry solving the task. The option "Show steps" does not give students the exact solution to the particular task.
- **Try another question like this one-** Numbas uses the set of variables defined by arbitrary mathematical expressions to randomly generate questions that are similar. With this, student have the opportunity to attempt similar questions many times until they feel confidence enough to move to the next question.
- **Reveal answer**- This section called advice section contains fully worked solution to the particular question. It provides step by step solution that is personalised to the question randomly generated question to the student. When a student decides to explore this option, they lose all the marks and cannot re-attempt the exact question. Again, the instructor may decide to disable this.
- **Statistics**- Numbas stores data of students' performance. This is particularly helpful to the teachers. They can track how well the students understand the topic through their performances, and they can equally identify the tasks students perform below expectations and reemphasis on them in the next class.

3. THEORETICAL FRAMEWORK

3.1 Activity Theory

Activity Theory has its root in the cultural-historical psychology work of Vygotsky. The primary ideas of the theory rests on a socio-cultural perspective in which learning is conceived as an offshoot of a dynamic relationship between the learner and the environment. With this perspective, learning is an appropriation of knowledge through a feedback relation between the learner and the environment (Vygotsky, 1978). Another fundamental concept of Activity Theory is the word 'activity' itself (Engeström, 2014). Leont'ev, 1978) defines an activity as any purposeful interaction between a *subject* (which could be an individual or group), and an *object*. The underlying assumption of the theory is that an *artefact* mediates the interaction between subject and object to give the desired outcome. More specifically, Numbas affordances are viewed from an Activity Theory perspective as a dynamic relationship between a goal-oriented user and the e-assessment system.

3.2 Affordances

The term 'affordance' was coined by James J. Gibson, who proposed the term to describe what the environment offers the animal, "what it provides or furnishes, either for good or ill" (Gibson, 1986, p. 127). Gibson argues that affordances 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, not just any property of the environment or whatever the environment can offer.

Affordances can be both objective and subjective, "they are objective because they exist independently of the act of perception, but they are also subjective because the frame of reference is the individual's action capabilities" (Osiurak, Rossetti, & Badets, 2017). Gibson further uses the concept of niche in ecology to refer to the set of affordances. He explains that "a niche refers more to how an animal lives than to where it lives". According to Hadjerrouit (2017, p. 213), "affordance is a relation between an organism and object with the object perceived in relation to the needs of the organism: cliffs afford falling off, small stones afford throwing, chairs afford sitting, door afford opening, etc.".

Norman (1988) introduced the concept of affordances in the Human-Computer-Interaction community. Norman's conceptualisation of affordances restricts affordances to an exclusive property of the object unlike Gibson's original conceptualisation. However, Norman reconsidered this position and embraces the fact that affordances are not an exclusive property of an object in isolation (Norman, 1999).

3.2.1 Emergence of Numbas Affordances

The object of the activity is the mathematical knowledge in the form of feedback received during the course of activity by the subject, e.g., the student. Within the activity system, the object provides reasons for the behaviours of the subject or , in other words, the subject uses artefacts to mediate activity so that the object can be achieved (Sexton & Lamb, 2017). As such, the mediating artefact is Numbas. It is important to remark that there is a thin line between the mediating artefact (Numbas) and the object (feedback delivery) in the present study because the former encloses the latter, unlike physical classroom objects, such as whiteboards and pointer that are used as mediators. Therefore, the outcome of a dynamic interaction (activity) between the subject (e.g., student), the object (feedback delivery), and the mediating artefact (Numbas) is the affordance of Numbas. In other words, Numbas affordances are not an exclusive property of the artefact and not completely determined by the subject. Instead, they emerge from a dynamic interaction between the artefact and the subject.

3.2.2 Perception of Numbas Affordances

Affordance perception of a given tool concerns its awareness by a goal-oriented user during the interaction. Affordance perception is conceptually different from its existence and it is logical to treat it as such (Greeno, 1994). It exists independently of the user's perception during interaction and can be perceived at varying levels of adequacy depending on contextually, socially, and technically motivated factors (Wang et al., 2018). 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 software. During this process, they become aware of the affordances that emerged during the interaction in terms of feedback delivery.

3.2.3 Actualisation of Numbas Affordances

Given the emergence and the perception of Numbas affordances, some questions are still waiting to be addressed: (a) How are action potentials turned into actions? (b) Does an action potential necessarily need to be perceived before being actualised?

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). 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 actualisation varies from one individual to another because it is goal-oriented and a process of specificity (Volkoff & Strong, 2017)

3.3 Affordances from an Activity Theory Perspective

Figure 2 presents the underlying theoretical framework that captures the emergence, perception, and actualisation of Numbas affordances. It is expected that following the actualisation of Numbas affordances are some consequences (effects). These consequences as Bernhard et al. (2013) put it may be "intended by the user and/or those by the original creator of the artefact as well as unintended effects" (p. 6). Moreover, it is important to highlight that the actualisation of Numbas affordances does not happen in isolation. In fact, affordances go along with constraints; they are facilitated by enabling conditions and hindered by constraints. In other words, affordances and constraints are inseparable because they complement each other, and not opposite.

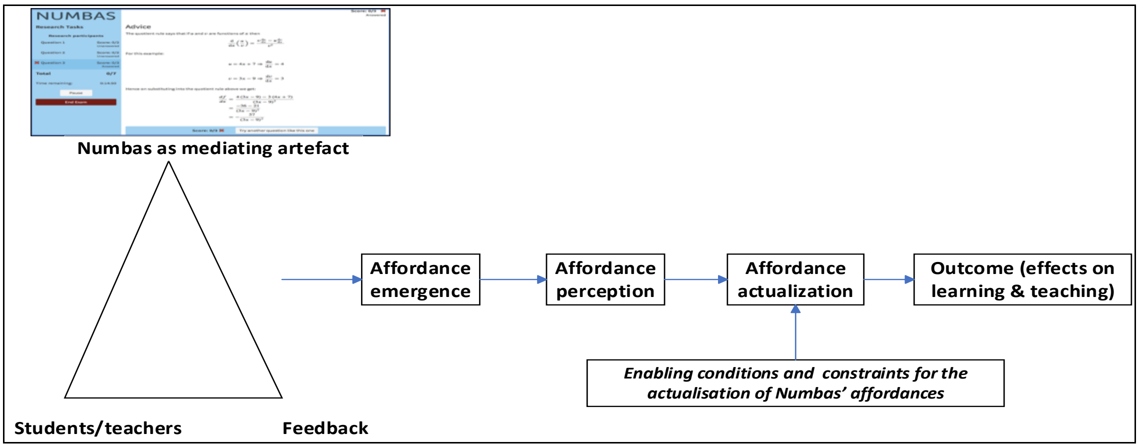

Figure 2. Affordances from an Activity Theory perspective

4. FINDINGS

From a methodological point of view, this work uses a case study to analyze the affordances perceived and actualized by the participants while interacting with Numbas. A thematic approach to data analysis is used to identify themes and codes within the data set (Bryman, 2016). Code development takes a deductive-inductive strategy consisting of an interplay between the pre-defined categorization of affordances and the empirical data that emerged inductively. Based on this analyse, this section presents a summary of the findings.

4.1 What affordances of Numbas are Perceived?

Interview data show that the students and teachers perceived various degrees of affordances of Numbas. Recall that an affordance is not an exclusive property of Numbas in isolation, rather it emerges in an activity system. Therefore, the affordances of Numbas are those outcomes of a dynamic interaction (activity) between the subject (student, teacher), the object (feedback delivery), and the mediating artefact (Numbas). The perception of the emerged Numbas affordances concerns the awareness by goal-oriented users (teachers and students) during the interaction. The students expressed their experiences in using Numbas to receive formative feedbacks to mathematical tasks, and the teachers indicated using Numbas to deliver formative feedbacks to their students.

From a technological point of view, the students and teachers responded that the user interface of Numbas is easy to use. During their interaction with Numbas, there was no confusions regarding the design of the interface. It looks simple and intuitive. Navigation to any page is also easy. They did not find it challenging to access feedback pages or submitting answers. The icons are visible with good and accurate inscriptions. Furthermore, they perceived that Numbas is Web-based, and that it can be accessed at any location or time, so long as there is internet coverage. They were also aware that Numbas has the facility to contain mathematical contents.

From a pedagogical point of view, the students and teachers perceived that Numbas affords variation in a way of displaying mathematical contents. They also perceived the affordances of Numbas to guarantee and increase students' autonomy, motivation, and engagement. They found the user friendliness and feedback mechanisms of the interface to be motivating. Potentialities to stimulate collaboration and contain collaboratives tasks, together with supporting individuals to learn at their respective paces were further perceived. They were also aware of Numbas potentials to support procedural understanding with high chances of supporting conceptual understanding. Some constraints of Numbas were perceived as well. Several forms of tests and assessment, including matrix, multiple choices, etc. with appropriate feedbacks were perceived. They further saw the possibilities of performing diagnostic teaching with the aid of Numbas.

From a teacher education point of view, both teachers and students perceived that Numbas will be useful to school teachers in achieving some of their teaching objectives. Therefore, they perceived that Numbas is adoptable to the new core curriculum for the mathematics subject.

4.2 How are the Affordances of Numbas Actualised?

The second question aims to address how the perceived affordances of Numbas are actualised (turned into actions) to bring effect(s) on the user. Recall that affordance perception and actualisation are treated as two distinct processes in this study, and in most cases, affordances are perceived before they are actualised.

At the technological level, students actualised the perceived affordances of ease of use, ease of navigation, overall accessibility, and facility to contain mathematical contents in several ways. Findings reveal that students were able to solve tasks and enter their answers in Numbas with ease. They also used the feedbacks mechanisms successfully. They easily navigated around by following inscriptions in the icons. Regarding accessibility, the students did formative assessments in Numbas from home without difficulties.

At the pedagogical level, students actualised the perceived affordance of variation by solving many mathematical tasks in different forms - graphical, diagrams, equations, etc. They copied out most of the tasks on paper, solved them using pen and paper, and consulted mathematics textbooks when necessary, before inputting the final answer(s) into the space provided by Numbas. The students actualised learner's autonomy to work in Numbas without assistance of their teachers by doing some tasks alone using only hints and other feedbacks from Numbas. However, they sought for the assistance of their fellow students, or the class teacher on some occasions. The feedbacks they received when they solved task in Numbas, especially the immediate feedback, together with user friendliness of the interface are the main source of motivation for the students. As for the affordances of collaboration, students worked in groups using Numbas in classroom. They also actualised higher order thinking when Numbas marked their correct answer wrong. In the quest to trace the error, they engaged in mathematical thinking. The students further solved different tasks and received various degrees of feedbacks along the line to actualisation of the perceived affordances.

The teachers actualised some of the affordances in a different way. This is due to their role as teachers and task creators. They relied on observations of their students to confirm the actualisation of some of the affordances. For example, they actualised 'ease of use' to create tasks but to a limited extent because they found it difficult to make complex tasks. They actualised accessibility by using Numbas at home, not just in school. In creating tasks, teachers made use of manuals provided by Numbas to create questions that include graphs, diagram GeoGebra worksheets etc, thereby actualising the perceived affordances of facility and variation. In terms of learner autonomy, students worked independently, but relied on the teachers to solve some tasks. The students worked in pairs using Numbas, thereby achieving collaboration. The teachers also used the statistical feedback from Numbas to inform their lessons and meetings with students.

4.3 What are the Constraints for the Actualisation of Affordances?

Findings from the students and teachers' interview data revealed that they actualised some of the perceived affordances that emerged but did not actualise others. In some cases, they actualised the affordances but not completely due to constraints. Findings reveal that insufficient navigation buttons, lack of internet connections are some constraints hindering full actualisation of perceived affordances at technological layers by the students. At the pedagogical level, the study found that teachers' poor knowledge to make comprehensive feedback. System glitch from Numbas, lack of features to save students' profiles to automatically assign tasks based on their performance progress, or support for collaboration from different locations, using different devices are some constraints hindering full actualisation of the affordances. At the teacher education level, they faced hindrance in a way that assessing conceptual understanding is difficult.

The teachers also found it challenging to make 'very good' tasks due to requirements of programming language. They also agreed with the students that internet could constrain the use of Numbas at any time and location. In terms of autonomy affordance, teachers believed that students' poor skills in the use of digital tools is a constraint. Teachers perceived the affordance of differentiation as a way of creating different levels of tasks, but could not actualised it due to time constraints. Other constraints include lack of features to save students' profiles and automatically assign tasks based on their performance progress, or support collaboration from different locations, using different devices.

5. DISCUSSION

The main goal of this study is to explore how Numbas promotes formative assessment for mathematics teaching and learning by assessing the affordances and constraints that emerge from interactions between teachers/students and Numbas. Three research questions were addressed towards achieving the goal. The first research question concerns the perception of Numbas affordances, the second concerns affordance actualisation, while the third one concerns the constraints. The study follows a qualitative research design in which data were generated using semi-structured interviews with six students and two teachers. The participants were familiar with Numbas and affordance theory. The designing of the interview guide was guided by the theoretical framework proposed for the study to collect data on the emergence, perception, actualisation of Numbas affordances, which are viewed from an Activity Theory perspective.

Findings reveal that the students were able to perceive and actualise several technological affordances of Numbas, such as ease of use and navigation, full accessibility, and facilities to contain mathematical knowledge. From a pedagogical point of view, the participants acknowledged that Numbas affords variation in mathematical contents, congruence with textbook mathematics, and support for the development of pen and paper skills. It was also acknowledged that Numbas could afford students' autonomy and motivation to engage in mathematical problem-solving. Numbas has constraints in the form of wrong marking of some correct answers, though in rare occasions. Surprisingly, this constraint is found to provoke mathematical thinking in most of the students. The feedback mechanisms are perceived to be very helpful and motivating. From an institutional point of view, Numbas suitability to be used in schools was perceived and recommended. Findings further show that Numbas is a very useful to promote formative assessment. This can be seen from the high level of affordance perception and actualisation, which in effect leads to formative feedback delivery. Clearly, user-friendliness of Numbas user interface supports the perception and actualization of affordances.

5.1 Limitations

The strength of the study is that affordances and constraints of Numbas have been studied in detail using semi-structured interviews as an instrument of data collection. However, the study is not without limitations. Firstly, the number of participants ($N=8$) is just one case of master's students and their teachers from a teacher education program of one university. The number is small when compared to the entire number of students and teachers using Numbas. Hence, a larger number of participants from several universities could have been more desirable to make better generalisation. Secondly, the participating students do not use Numbas for regular assessment in their own studies. Students using Numbas for day-by-day activities may have a different perspective about the affordance perception and actualisation processes, together with the constraints. Studies involving such set of students would be good to compare with findings of the presents report. Finally, Activity Theory has proved to be useful for arguing that the emergence of Numbas affordances is a result of a dynamic relationship between a goal-oriented user and the tool. Likewise, affordance theory has shown to be important in explaining the distinctiveness between affordance perception and actualisation. Moreover, the proposed framework has further shown to be a good guide for analysing affordances and constraints that emerge in an educational setting. However, the model as presented in the study is not intended to map all potential affordances and constraints, which is challenging, but it is open enough to capture potential affordances. This is the reason why the inductive approach to data analysis is so important.

5.2 Pedagogical Implications of the Research Findings

Globally, the findings indicate that Numbas is a useful tool for assessing mathematical 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 new mathematics subject curriculum with the sole intention of identifying possible problems and effecting necessary modifications along with improving the learning of students and the practice of teachers. For teachers, it is important to ascertain their role in using their skills and expertise for adding new methods of formative assessment, and identifying students learning progresses, while for students, it is important to focus on using Numbas as learning tool.

In educational settings, the role of Numbas should be clearly defined along with the role of teachers. For example, teachers need to identify why students need scaffolding when there are tasks assigned to them on Numbas. Teachers should also identify the role of personal feedback from Numbas in affecting the students' learning process. For students, it is important to weigh the learning effect in using teachers' ideas and Numbas explanations. From the university and school perspective, it is important to analyse whether Numbas is able to facilitate the acquisition of higher order thinking skills. Likewise, the focus should be on determining the cognitive load on the basis of higher or lower level of cognition. The responsibilities of teachers for improving students' learning using Numbas should be explained and defined properly. Such implications need to be further integrated for formulating a new strategy that will be able to support the formative assessment process.

5.3 Future Research Work

Overall, it can be said that the usefulness of Numbas is acknowledged by students and teachers, but the learning and teaching effects of the tool need to be further analysed. This requires the formulation of hypotheses to produce more generalizable findings. Firstly, there is a need to conduct quantitative analyses, by having a sample size that will be enough to represent the entire population currently using Numbas for regular assessment across universities or schools. Such analysis is crucial for adding more generalization to the study.

Secondly, it may be important to include a cross-national analysis by focusing on two countries using Numbas in their universities or schools and identifying the difference in affordance perceptions and actualisations. Such analysis will be helpful in determining the impact of socio-cultural factors on the acceptance and rejection of Numbas and justifying various affordances along with benefits and constraints. Finally, the validity and reliability of data is another factor requiring further attention. For example, rather than conducting interviews with students and teachers from one university, it may be useful to conduct interviews with participants from several universities where Numbas is being used.

6. CONCLUSIONS AND RECOMMENDATIONS FOR DESIGNERS

Numbas development is a work in progress, and the developers are working regularly to addressing concerns of teachers, students, and other users, as well as to improve the general design and functionalities. Recommendations for future development centre around addressing the constraints faced by teachers and students while using Numbas as a mediating artefact. Likewise, addressing the issue of insufficient navigation buttons by introducing 'next' and 'previous' buttons in the user interface. This could make navigating back and forth much easier. Furthermore, it may be important to improve the areas of support for group activities among students whereby students can work in pairs at different locations.

Furthermore, it is suggested that including features to make it possible for Numbas to save students' profiles and assign tasks to them based on their previous attempts. This might help greatly in the areas of allowing students work at their own pace. The study further recommends improving Numbas to be able to assess student's step-by-step solutions along with the final answers and provide feedback that will be personalised to the student's misconceptions. Numbas in its current level of development could be used to achieve many of the competence aims for the mathematics subject in the new core curriculum, in particular regarding the areas of assessing reasoning, proving, etc. Finally, the editor's user interface is recommended for improvement. This would encourage teachers to create tasks that best suit the need of their students.

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