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Published

2018

Conference Title

Proceedings of the 5th ERME Topic Conference (ETC 5) on Mathematics Education in the Digital Age (MEDA)

Version

Version of Record (VoR)

Link to published version

http://erme.site/topic-conferences/

Evaluation of Apps using the ACAT Framework

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Since the introduction of the first iPad in 2010, the overall number of apps and, consequently the number of apps intended to support mathematical learning, have increased exponentially. This observation results in the need for quality information about apps and also on the various possibilities for teachers to evaluate apps in an efficient and reliable way. Artifact-Centric Activity Theory (ACAT) is a model developed to capture complex situations that arise when digital technology is introduced in classroom situations. Furthermore, ACAT provides a framework to help teachers to evaluate apps. In this article we show how to use the ACAT framework for the evaluation of mathematics apps.

Keywords: Activity Theory. Apps. Primary Education. Geometry. Review.

TECHNOLOGY AND APPLICATIONS IN PRIMARY MATH EDUCATION

Digitization is both one of the most significant challenges, and also one of the most significant opportunities in today's world. This is also the case in educational contexts. When technology is used in a useful and goal-oriented way, it can help people to simplify everyday life as well as support various occupational routines. In the field of education, digitization can also help children to learn mathematics, a discipline that is often seen as difficult by many students (Larkin & Jorgensen, 2016). As in the broader societal context, the usefulness of technology in mathematics classrooms depends upon whether teachers are willing and able to take advantage of the potential of technology to support student learning.

The introduction and use of desktop computers in primary school has more or less failed for several reasons: one reason identified is that the hand-eye-coordination of young children is often insufficiently developed. That is why young children often have problems moving the mouse and coordinating the movements of their hands with their eyes and what happens on the screen (Ertmer, 1999; Kortenkamp & Dohrmann 2010; Ladel, 2017). This problem is exacerbated by the fact that the scale of the movements with the hand does not correspond to the scale of the appropriate movements on the screen (Ladel, 2017). With the introduction of the first iPad in 2010, these detrimental factors to student use of technology diminished or disappeared entirely. iPad technology allows the user to interact directly with the screen using their fingers and hence with the objects visually represented there. Thus, the obstacles of the insufficiently developed hand-eye-coordination of young children, as well as the different scales of mouse and screen, are no longer present. The haptic technology of the iPad (and similar tablets) is very suitable in supporting the learning of young children (See Alade et al., 2016; Sinclair & Bruce, 2015).

In addition to developments with iPad hardware, the software (Apps) has also developed rapidly in recent years. Whereas the software for personal computers was (and still is) very often restricted to drill-and-practice (especially in the field of arithmetic), many current iPad apps offer increased interactivity and a broader range of possibilities for discovery learning, particularly when used in authentic contexts with young children (Arnott, 2016). Although the rapid increase in the availability of apps is a potentially positive outcome for education, the negative aspect of this equation is that amongst the rapidly increasing number of apps, there is an overwhelming prevalence of inadequate or unsuitable mathematics apps (Larkin, 2016). As the need to identify good apps that support mathematical learning is therefore critically important; researchers, developers, as well as teachers require an efficient and reliable instrument to evaluate apps in an easy, yet thorough, way. One such instrument to do so, presented in this conference paper, is a review guide based on Artifact-Centric Activity Theory (ACAT) (Ladel & Kortenkamp, 2016).

THE ARTIFACT-CENTRIC ACTIVITY THEORY (ACAT)

Vygotsky and Leont'ev developed Activity Theory and this theory is based on the cultural-historical conception of human beings and their development. The interaction (activity) between human beings and the world (subject-object) is the primary focus of this theoretical framework and it is assumed that human beings are shaped in particular by their activities in the world (Nerdinger, Blickle & Schaper, 2014). In this way, activity is a process characterized by a constant transformation (Leont'ev, 1982) (see Fig.1).

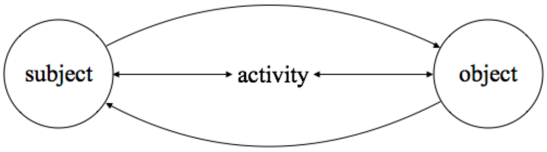

Figure 1. Ring structure of activity according to Leont'ev (In Nerdinger et al., 2014, p. 341)

It is understood that subjects (in this case children) have needs or objects (in this case learning about mathematics). In order to meet those needs they carry out activities and they achieve their object in an active way through object-oriented, changing and productive impacts. Thus, the activity is related to, and controlled by, the motive and is realized through object-oriented activities.

Vygotsky (1980) attributes an important role to mental tools in the interaction between subject and object. In the "so called" *instrumental act* (see Fig. 2), the mental tool mediates between the subject and the object.

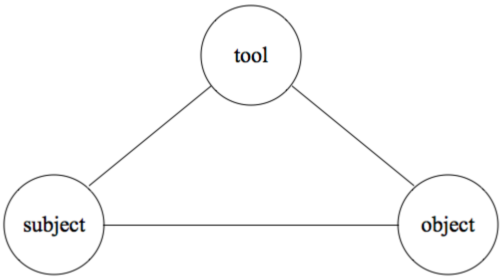

Figure 2. instrumental act

ACAT is a further development of Activity Theory and Activity Systems (where Community, Division of Labour and Rules are added to the initial Activity Theory triangle (Engeström, 1987) and is a methodological tool to understand the complex network of relationships in the interacting activity system of teaching and learning. The causal network of ACAT comprises five components (subject, artifact, object, rules, group), which interact with, and influence, each other in such a way that a change in any one of these components provokes a change in all other components. Central to ACAT is the artifact - a tool, an instrument or a mediating object - in this paper this artifact is the iPad or the iPad app. The main axis of subject-artifact-object includes the theoretical underpinnings of both Leont'ev's notion of activity as well as Vygotsky's instrumental act (see Fig. 3).

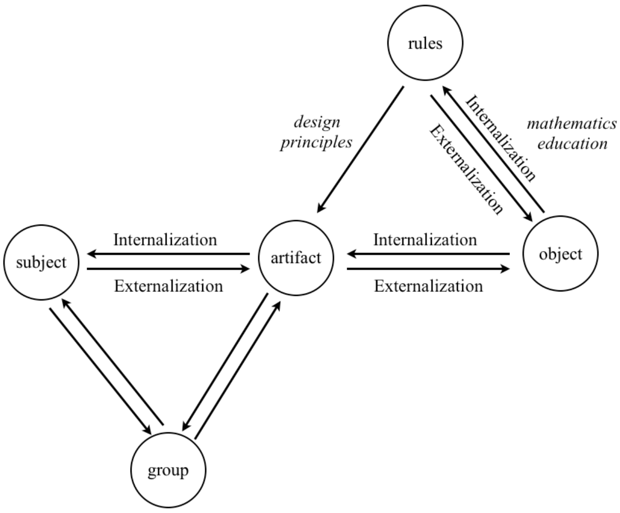

Figure 3. Artifact-Centric Activity Theory (Ladel & Kortenkamp, 2011, 2013).

The mediating artifact replaces the direct connection of subject and object with two connections, subject-artifact and artifact-object, as all interaction between subject and object is understood to be mediated by the artifact. This highlights the importance of the design and the analysis of the artifact for the activity (upper right triangle: artifact-object-rules).

The rules are primarily a result of the mathematical object itself, but they are also related to disciplines such as psychology, didactics of mathematics, or media didactics. The artifact represents the object itself, but simultaneously the object is encoded in the artifact and the properties and the aspects of the object limit the artifact.

The lower left triangle (artifact-subject-group) reflects the observation that the artifact does not only connect a human being with the object but also connects each individual with other human beings - the group. In this way the individual actions of the subject also include the experiences of other individuals in interacting with the artifact – in the case here this could include other students and also the teacher.

REVIEW OF APPS

ACAT is, therefore, a methodological tool to assist our understanding of the complex network of relationships in the interacting activity system of teaching and learning. Based on the assumption that ACAT could also help researchers and teachers to analyse and evaluate apps, we designed a review guide that should help them to easily evaluate apps and hence find the right ones to support their teaching and learning goals. The resulting review guide is organized into a sequence of five steps, following the main aspects of ACAT and principles of Activity Theory (Kaptelinin, 1996). This is similar to the approach of Kaptelinin et al. (1999), but differs in three ways: (1) The underlying model is specialised for analysing and designing artefacts and instruments; (2) The purpose of the guide is to help teachers without special training to judge whether a certain app can be useful for their pedagogical needs and thus includes specific instructions on how to answer the questions; (3) The guide is focused on education and not on Human Computer Interaction (HCI).

For each step, we formulated a key question that needs to be answered. In order to aid teachers in answering, we provide remarks and lead questions to consider, as well as possible data sources to find information regarding the five steps. The full development of the review guide is detailed in Larkin, Kortenkamp, Ladel and Etzold (2018, under review), whereas the review guide itself is available as an open educational resource at http://dlgs.uni-potsdam.de/oer.

Object orientation is a central principle of Activity Theory. All activities are directed towards an object. Hence it is important to know the object of the actions of students within an app precisely:

Step 1: What is the mathematical *object* of the app?	
Remarks	The reviewer identifies the mathematical object, i.e. the concept, content or mathematics process that is targeted by the app. Each app can address one or several mathematical objects.
Sources	Title and official description at iTunes Store; Additional material provided, e.g. downloadable worksheets; External references, e.g. recommendations by peers who have used the app; trials of app

In the process of designing an app, once the mathematical object has been established, the interaction design would be the next consideration. In the process of analysing an existing app, step 2 is used to examine the design of the user interaction:

Step 2: How do students *interact* with the mathematical object, mediated by the app?	
Remarks	What are the concepts that students have of the mathematical content? How do these concepts influence the use of the app? What possibilities and what limitations does the app have?
Sources	Own systematic testing of the app

Step 3 focuses on the *hierarchy* of activities, actions and operations, as well as conclusions about possible *developments* of students' interactions that influence their learning:

Step 3: How does the interaction *develop*?	
Remarks	What are the activities, the actions and the operations of the interactions?
Sources	Discussion of hypothetical scenarios; Empirical tests

The design of an app is guided by *rules* which in turn are guided by designer knowledge e.g. from mathematics education, HCI design, etc. Following those rules maximizes opportunities for the app to support learning of the targeted mathematical content:

Step 4: Is the app suitable for teaching and learning the mathematical object?	
Remarks	What insights do we have from mathematics specific pedagogy, the discipline of mathematics, and psychology? Do the previously analysed interactions support the desired or needed concepts, experiences and competencies?
Sources	Syntheses of the discussion above; Scientific background literature and references

Within ACAT, learning is never a purely individual activity of one single student. It must always be seen in a social and corporate context, in which learning content occurs by working together (group):

Step 5: How can the app be used in classroom instruction?	
Remarks	Is the app suitable for individual work, partner work or group work? What are possible impulses and tasks? What kind of differentiations and levels are possible? Is the goal of the app to train already understood content or is it intended to develop new concepts? Is the app based on an instructive or on a constructive paradigm? What are the competencies that the students need to work with the app?
Sources	Additional teacher's material; Trials with students; Imagination

In the appendix, we give an abridged example of an ACAT-based app review that was created by two teacher students following the above steps. Another in-depth example is available in Larkin et al. (2018, under review) and online.[1] In all these examples we can find conclusions that show how the reviewers come to deep conclusions based on their normal teaching skills. Also, we could see how the reviewers came up with suggestions for task design. They included suggestions for classroom integration of the app for students with special needs as well (in Step 5), which shows how the structure of the review guide helped them to come up with ideas for better teaching.

CONCLUSION AND FURTHER WORK

We propose an app review guideline that is based on the ACAT model. So far, this framework has been used for several reviews by German teacher students and proved useful for a theory-based approach without requiring in-depth training of the reviewers in ACAT. This is a welcome addition to more technical approaches that try to review apps based on non-pedagogic criteria such as number of features, configurability or technical soundness, or ad-hoc approaches that base the assessment on personal opinion or number of downloads. As an outcome of the project *Digitales Lernen Grundschule*, funded by Deutsche Telekom Stiftung, a German and English review guide and template were created and published as an Open Educational Resource.[2] Besides a platform to collect and publish ACAT based reviews, further work will include a systematic meta-evaluation of these reviews and the translation of the review guide and template to other languages.

APPENDIX: ACAT REVIEW FOR THE APP *SHAPES 3D – GEOMETRY LEARNING*

(Abridged translation of the original review Deßloch, L. & Hoffmann, L.-M., 2018)

App: Shapes 3D – Geometry Learning, *Version* 2.2.2. (Published 30th of June, 2017). At the App-Store intended users can find a lengthy description of the app, information regarding additional material to support its use, as well as rewards the app has won. Due to space limitations we have not included this information here and have only provided an abridged version of the teacher student review.

Step 1: What is the mathematical *object* of the app? The mathematical object of the app is to identify the spatial imagination in relation to geometric solids. The focus lies on the connection between the three-dimensional solid and the two-dimensional solid-net.

Step 2: How do students *interact* with the mathematical object, mediated by the app? Students choose one of the 27 solids offered by the app to explore them. They can move and scale them as well as rotate them using touch gestures. Using a swipe gesture or touches the solid can be unfolded dynamically or step-by-step into a net. Several nets for each solid are offered and more can be created by the student. Nets can be printed, with additional glue flaps added. Furthermore, the faces, vertices and edges of the nets can be colored.

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[2] http://dlgs.uni-potsdam.de/oer

Step 3: How does the *interaction* develop? The students' actions manifest themselves as goal-directed, individual interactions on physical and virtual manipulatives. The combination of physical and virtual manipulatives leads to a (further) development of the spatial imagination, which results in the fact that the concrete actions gradually pass into operations and thus into internalized actions.

Step 4: Is the app suitable for teaching and learning the mathematical object? The consistent representation of the user interface is self-explanatory and intuitive for the learner as well as the symbolic representation. Dynamic elements for representing interactions also serve to intuitively interact with the touch device. In terms of mathematic didactics, it should also be emphasized that the principle of the spiral curriculum can be applied to the app, in particular due to the high number of geometric solids and the varying complexity. In this way, more and more geometric solids can be explored.

Step 5: How can the app be used in classroom instruction? For a meaningful use of the app in primary school, the students should have basic experience with and basic knowledge of geometric solids. Regarding knowledge transfer, the app supports the acquisition of conceptual knowledge related to the properties of geometric solids or solid groups as well as the nature of solid-nets. Regarding procedural knowledge, the app promotes knowledge about the composition of a solid’s net, the relationship between two-dimensional solid-nets and the corresponding three-dimensional solids, and the relationships between the properties of a geometric solid.

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