USABILITY IMPROVEMENT OF A MOBILE GRAPHING CALCULATOR APPLICATION

Melanie Tomaschko and Markus Hohenwarter

Johannes Kepler University Linz, Austria; Melanie.Tomaschko@jku.at, Markus.Hohenwarter@jku.at

Previous research has established that the integration of mobile technologies and related mobile applications in mathematics education can enhance learning in various ways. Additionally, there is a growing body of literature that recognises the importance of the usability of educational mobile applications. Thus, it is important to study how these mobile applications can be designed and developed in order to best support the impact on educational achievements. This paper presents an overview of possible usability issues of mobile graphing calculator applications and provides recommendations on how to overcome these concerns. The contribution of this paper is to propose helpful suggestions for designers and developers of mobile mathematics applications in order to develop easy to use applications that best support mobile technology enhanced learning in mathematics education.

Keywords: GeoGebra, Graphing Calculator, Mobile, Usability

INTRODUCTION

The integration of Information and Communication Technology (ICT) in educational settings has gained a lot of interest. Previous research indicates that the integration of technology in educational environments is essential for high-quality mathematics (Burrill, 2011; NCTM, 2008; Pimm & Johnston-Wilder, 2005). Thus, there exists an increased demand for teachers to develop learning environments that enable opportunities for the integration of technological tools and digital learning resources in their classroom settings (Bachmair, 2013; Kerres, Heinen & Stratmann, 2012; Lim, Zhao, Tondeur, Chai & Tsai, 2013). Because of the advancing popularity of mobile devices, especially smartphones, among students (MPFS, 2018) great opportunities are offered to complement traditional education with these devices and enrich students' learning in various ways. However, it is particularly important to develop mobile applications with high usability in order to exploit the full potential of mobile learning in mathematics classrooms and to best support learning outcomes. In this regard, Deegan and Rothwell (2010) highlight the importance of cognitive load theory. The authors point out that a poor usability of the deployed mobile application can cause extraneous cognitive load and thus waste the limited resources of the learners' working memory. Respectively, high usability of educational mobile applications can reduce the cognitive load, because learners can focus on the educational content instead of directing cognitive load toward using the application (Deegan & Rothwell, 2010; Reis et al., 2012). For this reason, the main purpose of this paper is to present possible usability issues of mobile graphing calculator applications and to provide suggestions for an improved user interface and interaction design. In order to achieve this objective, the GeoGebra Graphing Calculator (2019) application for smartphones was investigated (see Tomaschko & Hohenwarter, 2018). Therefore, qualitative and quantitative evaluation methods were used. Hence, a set of usability issues that learners encountered while interacting with the mobile application were identified. The revealed study findings were considered for a comprehensive revision of the mobile GeoGebra Graphing Calculator application. As a result, the usability of the mobile application could be improved. This paper presents the revealed usability concerns as well as recommendations and hints

that could be considered from designers and developers of mobile mathematics applications in order to increase the impact on educational achievements

GEOGEBRA GRAPHING CALCULATOR

In this section, the GeoGebra Graphing Calculator (2019) application is introduced. This application was investigated on a smartphone in order to reveal potential usability issues of mobile graphing calculator applications (see Tomaschko & Hohenwarter, 2018) that are presented in this paper.

GeoGebra[1] provides a set of dynamic mathematics software tools that are used by millions of students and teachers worldwide. These open source applications can support the teaching and learning of geometry, algebra, spreadsheets, graphing, statistics, and calculus. GeoGebra was first developed as desktop application for the operating systems Windows, MacOS X, and Linux and later as HTML5 web application running in all modern browsers. In 2015, the development of fully native applications for the platforms Android and iOS has been started. These applications are based on the existing source code of GeoGebra's mathematical algorithms, however the user interface was modified in order to address the special requirements of smartphones, in particular their smaller screen size.

The GeoGebra Graphing Calculator (2019) application offers typical functionalities of a graphing calculator such as an equation editor, a virtual keyboard, and a set of geometrical construction tools. After starting the application, the graphics and algebra views are displayed on the screen. The algebra view provides an equation editor and a custom virtual keyboard to facilitate the input of complex mathematical expressions (see Figure 1 left). In addition to the algebraic possibility to construct new mathematical objects, geometrical construction tools are offered that can be used to construct new objects within the graphics view (see Figure 1 middle). All of the created objects are represented in both views (see Figure 1 right) and are dynamically connected, which means that modifications in one view are immediately displayed in the other one as well (Kimeswenger & Hohenwarter, 2015).
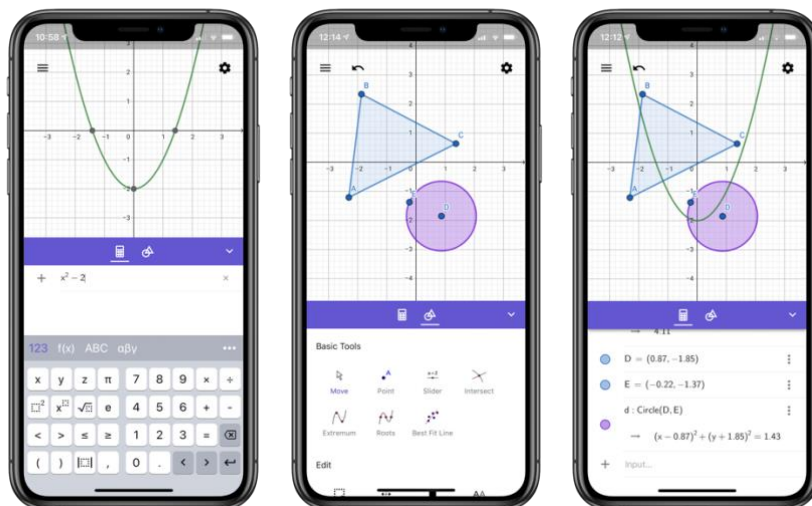

Figure 1. Screenshots of the GeoGebra Graphing Calculator (Version from February 2019)

SUGGESTIONS FOR USABILITY IMPROVEMENTS

Based on previous usability studies (see Tomaschko & Hohenwarter, 2018), the GeoGebra Graphing Calculator was extensively redesigned and revised. As a result, a measurable improvement of the

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[1] GeoGebra. www.geogebra.org, last visited Feb. 14, 2019.

application's usability could be achieved. In this section, we describe the revealed usability concerns and present solutions on how to overcome these issues. Even though the undergone study and revision were undertaken with the GeoGebra Graphing Calculator application, they are relevant for any educational application that offer the input of mathematical expressions or geometrical construction tools.

Math Keyboard and Equation Editor

The GeoGebra Graphing Calculator application provides an equation editor and a custom virtual keyboard for mathematical input. As this is one of the most important features of a graphing calculator, it is essential to guarantee high usability and to aid users in typing mathematical expressions.

In order to improve the input of mathematical expressions and reduce potential sources of errors it is essential to offer appropriate labels for all keys that are displayed on the keyboard. What we have learned from a previous study, it is important that all symbols that are not inserted into the equation editor after pressing a certain key should be clearly distinguishable from characters and symbols that are actually inserted. If the keyboard would offer a key for the power of two labeled as x^2, users would expect that the character x as well as the exponent is inserted into the equation editor, which is not the case. Similar problems can encounter if other characters are used in order to indicate a placeholder. As shown in Figure 2 (left) the keyboard offers a key for the input of an exponent labeled as a^x. However, users do not recognize the purpose of this button. These problems can be rectified by using special placeholders such as dashed squares. Figure 2 shows a comparison of a keyboard that uses characters (left) and dashed squares (right) as placeholders.
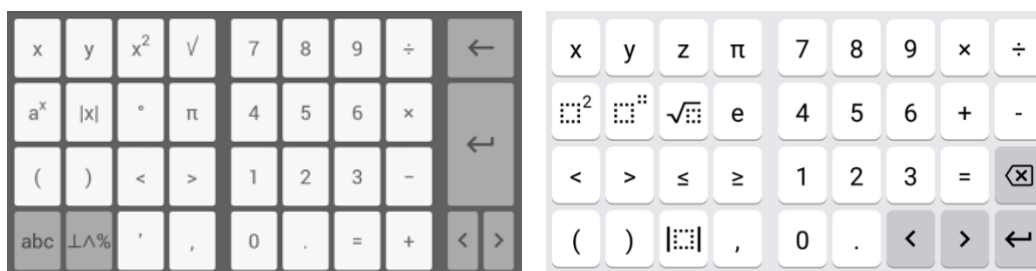

Figure 2. Keyboards that use characters (left) and dashed squares (right) as placeholders

To optimize the input of exponents, we suggest for specific use cases to automatically align the cursor again to the baseline after a specific user input. Otherwise, it is more likely that users keep typing without recognizing that the cursor is still set to superscript. This requires to revise the input and to remove the already typed characters. For this reason, we suggest that the cursor is again aligned with the baseline as soon as the user presses the plus or minus button (except in parenthesized expressions, including square root or absolute value, and as algebraic sign). Because a functional equation of the form $x^{number+number}$ would be unusual in secondary school, this expression could automatically be recognized and set to the more common form of $x^{number} + number$. The same applies to subtractions of numbers in such exponents. However, as divisions and multiplications are commonly used in such exponents in schools, the cursor should stay superscript in these cases.

In order to further improve the interaction with the equation editor, we suggest to support an interaction with the equation editor as it is known from common text fields on mobile devices with a touchscreen. This includes for example the precise positioning of the cursor by tapping with the finger at a specific position. Additionally, touch gestures such as holding and dragging to open a zooming

lens (see Figure 3) could be offered to facilitate the precise movement of the cursor. Thereby, the zooming lens is slightly shifted upwards, so that it is not covered by the finger.
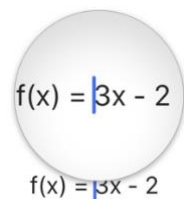

Figure 3. Zooming lens

If the mobile application offers a possibility for calculating an integral, we recommend to offer multiple options to conduct this operation. Users tend to search the keyboard for an integral button as they may already know from traditional graphing calculators. Thus, we suggest to add an integral button on the keyboard. For applications that offer geometrical construction tools, it could also be considered to offer a tool for the integral.

Geometrical Construction Tools

Based on our prior research studies (Tomaschko & Hohenwarter, 2018), we can recommend the use of a grid layout for construction tools, especially if the mobile application offers a large number of different tools. For the representation of the tools it is important to provide an image as well as caption text. Particularly for novice users it is important to offer the name of the tool, as offering images only may not be indicative enough. In contrast, already experienced users tend to search for the already known icon of the tool. Figure 4 shows an example of a grid layout with construction tools that display an icon as well as the name of the tool.
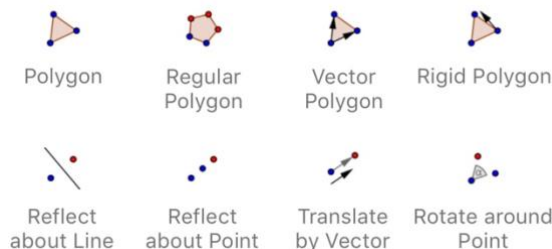

Figure 4. Representation for Geometrical Construction Tools

For mobile applications that offer a set of construction tools, it should also be considered whether to use sticky tools or not. The GeoGebra Graphing Calculator application uses sticky tools, which means that after a tool has been selected it "sticks" and can be used multiple times. However previous research investigations (Tomaschko & Hohenwarter, 2018) have shown that if a tool is used to create multiple objects directly one after the other, the tool is almost always selected again. Therefore, it could be considered to automatically deselect the tool after the object is created. This could further improve the usability, because with sticky tools users often "forget" that a tool is still selected and accidentally create new objects while they are trying to move an existing object or zoom the graphics view. This requires additional interactions of the user, as they have to reverse these unintentional constructions.

For the construction of an angle, the GeoGebra Graphing Calculator offers different possibilities: by selecting three points, two segments, two lines, etc. Thereby, the order of selecting these objects is relevant. However, it often happens that users select the objects in the wrong direction and thus

construct the exterior instead of the interior angles. For simple objects such as triangles this could be solved by defining a default interval between 0° and 180° for the angles. This guarantees that always the interior angles are constructed, no matter in which direction the objects were selected.

For more complex tools that require multiple steps to be completed, users require further support in the construction process. GeoGebra offers short information texts describing how a certain tool can be used. However, this is not invariably helpful. In order to create a parallel line for example, it is required to first create a line. Only after the line is created the *Parallel Line* tool can be used to select the previously created line and to construct a new point through which the parallel line should go. To improve the construction process for such complex tools, a possible solution could be a step-by-step guide for users (see Figure 5).
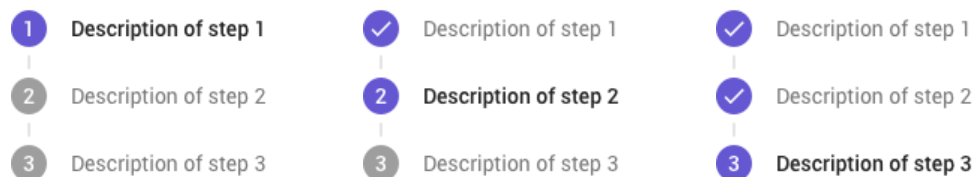

Figure 5. Step-by-Step instructions

Further Improvements

Even though the GeoGebra Graphing Calculator application offers two possibilities to delete existing objects, it is not always easy for users to find these functionalities. GeoGebra allows to delete objects using the delete tool from the tools view or using the small cross displayed at the end of each algebra view row. From previous research (Tomaschko & Hohenwarter, 2018) it could be observed, that users first try to select the object within the graphics view or to open the corresponding properties of the object. For this reason, we suggest to provide a small context menu for each object as soon as it is selected from the graphics view (see Figure 6). This context menu should contain an opportunity to delete the object and also frequently used properties. This way of providing access to the properties of an object can further improve the usability of the application. Another opportunity would be to long tap an object in order to open a properties view of the object. However, this may not be sufficient for users, as they are often interrupted in their construction process while moving objects or the graphics view because the touch gesture is recognized as a long tap and the properties view is opened.
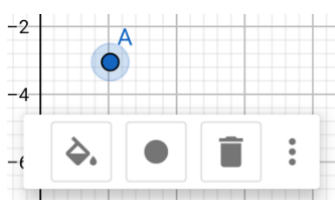

Figure 6. Context menu for objects

While users are creating new objects within the graphics view, they often try to zoom the graphics view by pinch-zooming while a construction tool is active. In this case, it is important to automatically recognize such gestures and to not apply the currently selected tool. Because otherwise, instead of zooming the view, new objects would be created. In this case users would have to interrupt their construction process and delete the accidentally created objects before being able to continue.

CONCLUSION

This paper presented several usability issues students may be facing while interacting with a mobile graphing calculator application which were found in previous eye-tracking research studies. Furthermore, recommendations on how to best design such applications for educational purposes in order to improve the usability of the mathematics application were given. The main contributions of this paper is to provide suggestions for an improved interaction and user interface design. Hence, we hope that our presented study findings will be informative for other researchers and designers willing to develop easy to use mathematics applications and to further extend the research on the usability of mathematics applications.

REFERENCES

Bachmair, B. (2013). Auf dem Weg zu einer Didaktik mobilen Lernens. *Schulpädagogik Heute. Digitale Medien Und Schule*, *7*, 1–16.

Burrill, G. (2011). ICT in the United States: Where We Are Today and a Possibility for Tomorrow. In A. Oldknow & C. Knights (Eds.), *Mathematics Education with Digital Technology* (pp. 12–22). London, New York: Continuum International Publishing Group.

Davids, M. R., Chikte, U. M. E., & Halperin, M. L. (2014). Effect of improving the usability of an e-learning resource: a randomized trial. *AJP: Advances in Physiology Education*, *38*(2), 155–160.

Deegan, R., & Rothwell, P. (2010). The application of Cognitive Load Theory to the usability of m-learning applications: First steps. In *Proc. IHCI* (pp. 69–72).

GeoGebra Graphing Calculator (2019). Google Play Store. Retrieved from: https://play.google.com/store/apps/details?id=org.geogebra.android

Kerres, M., Heinen, R., & Stratmann, J. (2012). Schulische IT-Infrastrukturen: Aktuelle Trends und ihre Implikationen für Schulentwicklung. *Jahrbuch Medienpädagogik 9*, 161–174.

Kimeswenger, B., & Hohenwarter, M. (2015). Interaktion von Darstellungsformen und GeoGebra Books für Tablets. In: Roth J., Süss-Stepancik E., Wiesner H. (Eds.), *Medienvielfalt im Mathematikunterricht*. Springer Spektrum, Wiesbaden.

Lim, C. P., Zhao, Y., Tondeur, J., Chai, C. S., & Tsai, C.-C. (2013). Bridging the Gap: Technology Trends and Use of Technology in Schools. *Educational Technology & Society*, *16*(2), 59–68.

MPFS - Medienpädagogischer Forschungsverbund Südwest. (2018). *JIM-Studie 2018*. Retrieved from https://www.mpfs.de/fileadmin/files/Studien/JIM/2018/Studie/JIM_2018_Gesamt.pdf

NCTM. (2008). The Role of Technology in the Teaching and Learning of Mathematics. *National Council of Teachers of Mathematics*.

Pimm, D., & Johnston-Wilder, S. (2005). Technology, mathematics and secondary schools: A brief UK historical perspective. In S. Johnston-Wilder & D. Pimm (Eds.), *Teaching Secondary Mathematics with ICT* (pp. 3–17). Maidenhead: Open University Press.

Reis, H. M., Borges, S. S., Durelli, V. H. S., Fernando De S. Moro, L., Brandao, A. A. F., Barbosa, E. F., … Bittencourt, I. I. (2012). Towards reducing cognitive load and enhancing usability through a reduced graphical user interface for a dynamic geometry system: An experimental study. *Proceedings - 2012 IEEE International Symposium on Multimedia, ISM 2012*, 445–450.

Tomaschko, M., & Hohenwarter, M. (2018). Usability Evaluation of a Mobile Graphing Calculator Using Eye Tracking. In *Proceedings of the 5th International Conference on Learning and Collaboration Technologies.* Las Vegas, Nevada.

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