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AUGMENTED REALITY-TOOLKIT FOR REAL-TIME VISUALIZATION OF ELECTRICAL CIRCUIT SCHEMATICS

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The contribution is centred around the presentation of the didactical concept and the technical implementation of a toolkit for real-time visualizations of electrical circuit schematics with Augmented Reality (AR) for physics education. After an introduction to the state of research on learning with AR in physics education, the didactical curriculum and the specific learning difficulties of electrical circuit schematics from introductory to higher level physics education are expounded. Subsequently, the technical features of the toolkit are explained. The major technical feature of the toolkit is the dynamic real-time visualization of electrical circuit symbolics: electrical circuit symbols of components and electrical circuit schematics of (parts of) electrical circuits can be perceived in real-time during the circuit assembly. Lastly, pending technical improvements are discussed and an outlook concerning the practical implementation of the toolkit is given. Overall, this contribution provides insights into current didactical design potentials and prevailing challenges concerning the use of AR-technology in physics education.

Keywords: Dynamic visualization tools, Educational Technology, Physics

THEORETICAL BACKGROUND

Augmented reality in physics education

Augmented Reality (AR) allows for simultaneous perception of real and digitally generated information (Azuma, 2001). It can be understood as a concept for computer-generated environments (Silva et al., 2003), where the real environment as the initial channel of perception is enriched with spatially and/ or semantically connected virtual information (Milgram & Kishino, 1994) to provide supplementary information in real-time (Liu et al., 2006). The most used AR-technology in educational contexts is display-based AR, where a handheld device (e.g., smartphone or tablet) is used to present AR, whereas head-mounted display-AR devices (hereafter referred to as HMD devices) are still little used (Akçayır & Akçayır, 2017). The HMD devices allow for the perception of virtual objects in the direct field of view and leave the hands free for other activities (e.g., the conduction of scientific experiments). AR has emerged as a technology in teaching and learning during the past years and has so far shown potential for applicability in different educational and pedagogical contexts: AR can promote the acquisition of knowledge and skills (Arici et al., 2019; Garzón & Acevedo, 2019), and it can have a positive influence on motivation and engagement (Zhang et al., 2020). However, the use of AR can entail technical difficulties and may result in a prolonged instruction time for both teachers and students (Munoz-Cristobal et al., 2015). Results by Wu et al. (2013) on the implementation of AR in education suggest that overall, not the implementation of AR itself, but the didactical embedment of AR determines the success of learning. The use of didactically substantiated AR technology for physics education, especially AR-supported physics experiments, reduced cognitive load by integrating real and digital information in the learner's field of view (Thees et al., 2020) and resulted in a higher learning gain compared to a non-AR-setting (Altmeyer et al., 2020). An AR-tool for laboratory experimentation on magnetism by Adusselam & Karal (2020) increased students' academic achievements and facilitated learning. The authors further suggest using AR as a supplemental tool for real-world activities rather than a standalone AR-environment. Permana et al. (2019) published a learning book on electricity that is enriched with animations, sounds and videos by the help of AR. Weatherby et al. (2020) described the concept of an AR-application for real-time visualization of the electrical potential modelled as a height profile alongside the physical circuit. The described real-time integration of spatially and semantically connected information in the field of view by means of AR holds potential to be transferred to other fields of physics education, as shown below.

Difficulties of learning circuit schematics

Although electrical circuit schematics provide a simple, structured symbolic representation of electrical circuits, the understanding and usage of electrical circuit schematics from introductory physics education up to early secondary level physics education can be impaired by various causes: Apart from matching the physical components with the corresponding symbolics, a crucial difficulty lies in the discrepancy between the (rather functional) spatial arrangement of the tools and the clear, often simplified structure of the corresponding circuit schematic (Wilhelm & Hopf, 2018). On the one hand, multiple possible circuit schematics can be drawn based on a single given serial circuit (see Figure 1a). On the other hand, multiple spatial arrangements within a parallel circuit can correspond to the same given circuit schematic (see Figure 1b).

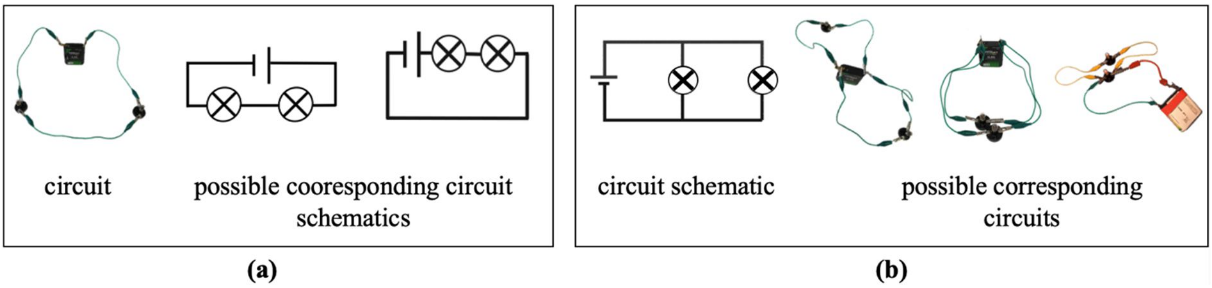


Figure 1. Examples for discrepancies between circuit and corresponding circuit schematics: (a) starting from a given circuit, (b) starting from a given circuit schematic.

The described discrepancies between the spatial arrangement of the tools and the simplified structure of the circuit schematic may obstruct the formation of cognitive connections between the circuit components/ the circuits and their symbolic representations. However, the establishment of representational competencies concerning the shift between physical and symbolic representations of electrical circuits is essential for a beneficial use of circuit schematics. As physics experimentation skills in secondary education can be positively influenced by early-age acquisition of knowledge on physics experimentation (Stern et al., 2015), those competencies should be fostered from an early age on. In higher physics education, however, electrical circuit schematics serve more as a structural aid for the use of complex electrical circuits.

AR-TOOLKIT DEMONSTRATION

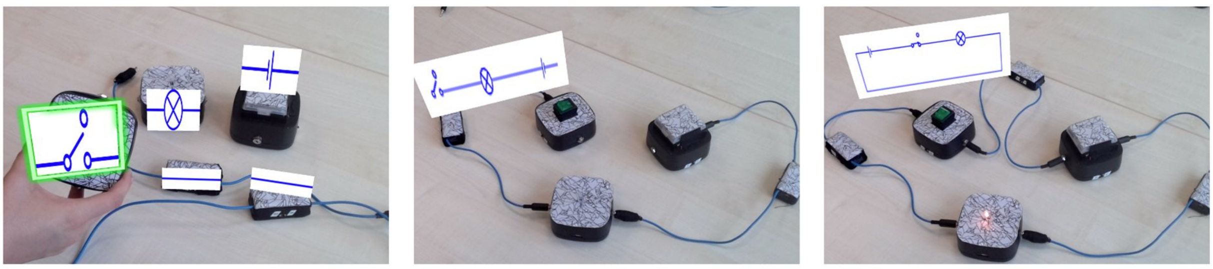
Technical Features

To facilitate the learning of electrical circuit schematics and to ease the prevailing learning difficulties, an AR-toolkit to provide real-time visualization of electrical circuit symbols and circuit schematics was designed (Lauer et al., 2020). The components of the toolkit are specially designed boxes with plugs on the sides for establishing cable connections (see Figure 2). Currently available components are lightbulbs, batteries, cables and switches. All components are covered with visual markers as explained later.

(a) (b) (c) (d)

Figure 2. Components of the AR-toolkit: (a) lightbulb, (b) switch, (c) battery, (d) cable.

The toolkit allows for real-time visualization of single component symbols and circuit schematics of unfinished and full electrical circuits (see Figure 3). A visual touch-highlight (see Figure 3a) emphasizes the connection between component and symbol and offers visual orientation when handling many components at a time. The structure of the circuit schematic displays the physical connection of the tools rather than their spatial arrangement in order to always present the semantically correct, but structurally most simplified circuit schematic.



(a) (b) (c)

Figure 3. Real-time visualization of symbolics for electrical circuits: (a) visualization of symbols for single components with green touch-highlight, (b) visualization of the schematic for unfinished circuits, (c) visualization of the schematic for full circuits.

The real-time visualization is enabled via wireless communication between the boxes, a server and the mobile AR-device (see Figure 4). The component boxes are distinctively designed so that they can be identified, and their physical connection can be determined at any time during circuit assembly. The information concerning the physical connection of the components is passed on via the wireless network to an application on a computer which calculates the appearance of the corresponding symbols and/ or schematics that are to be displayed. The formerly mentioned visual markers are uniquely assigned to the components and thus serve as the spatial positioning anchor for the corresponding symbols and schematics. In this way, the symbols and schematics can be perceived as virtual objects in spatial proximity to the real components or circuits and their appearance adapts in real-time when the physical components are moved or when their connection is modified.

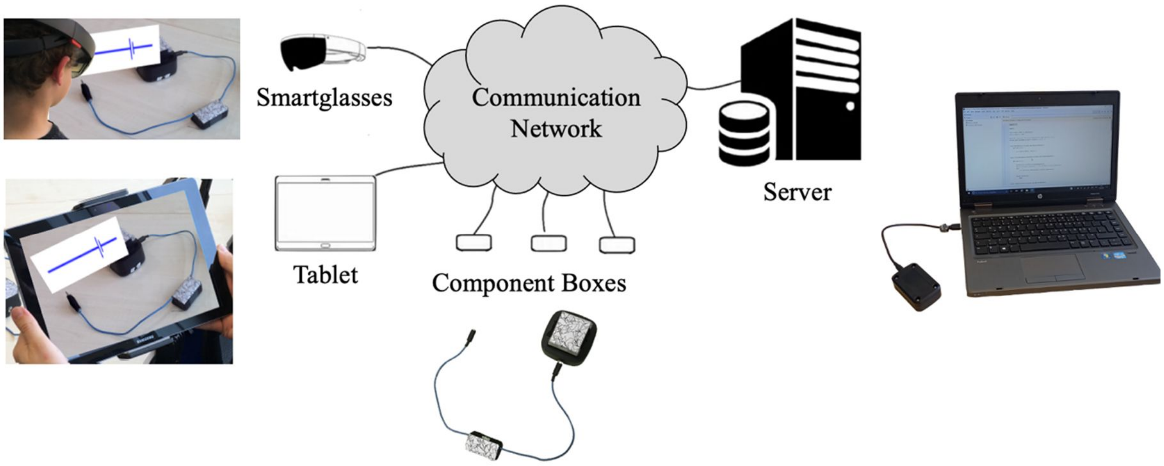


Figure 4. Schematic depiction of the wireless communication network for the real-time visualization of the symbolics via AR.

The toolkit is compatible with both handheld tablet-devices and HMD devices. In the case of handheld tablet-devices, the AR is created by integrating the virtual symbolics and schematics into the camera view of the device. The tablet must be either mounted on a stand (which reduces the mobility) or it must be held in the hand (which impairs the simultaneously ongoing circuit assembly process). As the HMD-devices are mounted on the user's head, they leave the hands free for the physical circuit assembly and create an AR-experience where the symbols and schematics are seemingly integrated into the direct field of view. However, this technology is not yet widely used in education, not least because of the high cost.

Fields of application

The presented AR-toolkit aims at encountering the described difficulties of understanding electrical circuit schematics in introductory physics education. It is suitable for introducing students to the schematic symbols and for step-by-step explanation of the circuit semantics regarding the process of abstraction from the electrical circuit to the simplified circuit schematic in primary school or early secondary school physics education. A major pending development is the detection and visualization of parallel circuits. The aim is to enable the toolkit to distinguish serial from parallel circuits and to adapt the display of the circuit schematics accordingly. The toolkit could then be used in early secondary physics education to support the differentiation between serial and parallel circuits. In higher physics education, the use of the toolkit shifts from a teaching-function to an assistive function. It could be used to keep track of complex connections between components.

Summary and Outlook

Overall, the use of didactically substantiated AR-technology in physics education holds potential to facilitate the acquisition of (representational) competencies by connecting objects of the real world with additional virtual information in real-time. The presented AR-toolkit for real-time visualization of electrical circuit schematics represents a first-stage prototype of such a use case. However, further technical optimization is required to enable its use in everyday scholar education and training. Therefore, the following technical improvements are planned or are being carried out: the underlying software will be optimized to handle a larger number of active components at a time. This is necessary as regarding the current version, the reaction time of the display of AR-schematics and symbols increases significantly with the number of active components. For the practical use in everyday educational situations, a reduction of the box size and an assimilation to the appearance of common electrical tools in education should be taken into consideration.

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REFERENCES

Abdusselam, M. S., & Karal, H. (2020). The effect of using augmented reality and sensing technology to teach magnetism in high school physics. *Technology, Pedagogy and Education, 29*(4), 407–424. https://doi.org/10.1080/1475939X.2020.1766550

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20*, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Altmeyer, K., Kapp, S., Thees, M., Malone, S., Kuhn, J., & Brünken, R. (2020). The use of augmented reality to foster conceptual knowledge acquisition in STEM laboratory courses—Theoretical background and empirical results. *British Journal of Educational Technology*, *51*, 611–628. https://doi.org/10.1111/bjet.12900

Arici, F., Yildirim, P., Caliklar, Ş., & Yilmaz, R. M. (2019). Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis. *Computers & Education*, *142*, 103647. https://doi.org/10.1016/j.compedu.2019.103647

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *IEEE Computer Graphics and Applications*, *21*(6), 34–47. https://doi.org/10.1109/38.963459

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of Augmented Reality on students' learning gains. *Educational Research Review*, *27*, 244–260. https://doi.org/10.1016/j.edurev.2019.04.001

Kapp, S., Thees, M., Strzys, M. P., Beil, F., Kuhn, J., Amiraslanov, O., Javaheri, H., Lukowicz, P., Lauer, F., Rheinländer, C., & Wehn, N. (2019). Augmenting Kirchhoff's laws: Using augmented reality and smartglasses to enhance conceptual electrical experiments for high school students. *The Physics Teacher*, *57*(1), 52–53. https://doi.org/10.1119/1.5084931

Lauer, L., Peschel, M., Malone, S., Altmeyer, K., Brünken, R., Javaheri, H., Amiraslanov, O., Grünerbl, A., & Lukowicz, P. (2020). Real-time visualization of electrical circuit schematics: An augmented reality experiment setup to foster representational knowledge in introductory physics education. *The Physics Teacher*, *58*(7), 518–519. https://doi.org/10.1119/10.0002078

Liu, W., Cheok, A. D., Hwee, S., & Ivene, A. (2006). Mixed Reality for Fun Learning in Primary School. *Proceedings of the 2006 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology, June 14-16, Hollywood, California.*, 1. http://dl.acm.org/citation.cfm?id=1178823

Milgram, P., & Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information Systems*, *E77-D*(12). http://vered.rose.utoronto.ca/people/paul_dir/IEICE94/ieice.html

Munoz-Cristobal, J. A., Jorrin-Abellan, I. M., Asensio-Perez, J. I., Martinez-Mones, A., Prieto, L. P., & Dimitriadis, Y. (2015). Supporting Teacher Orchestration in Ubiquitous Learning Environments: A Study in Primary Education. *IEEE Transactions on Learning Technologies*, *8*(1), 83–97. https://doi.org/10.1109/TLT.2014.2370634

Permana, A. H., Muliyati, D., Bakri, F., Dewi, B. P., & Ambarwulan, D. (2019). The development of an electricity book based on augmented reality technologies. *Journal of Physics: Conference Series*, *1157*, 032027. https://doi.org/10.1088/1742-6596/1157/3/032027

Silva, R., Oliveira, J.C., & Giraldi, G.A. (2003). Introduction to augmented reality. *Natl. Lab. Sci. Comput. 11*, 1–11.

Stern, E., Edelsbrunner, P., Schumacher, R., & Schalk, L. (2015). *Physics instruction in elementary school can boost general experimentation skills*. the 16th Biennial Conference for Research on Learning and Instruction (EARLI), At Limassol, Cyprus. https://www.researchgate.net/publication/280044259

Thees, M., Kapp, S., Strzys, M. P., Beil, F., Lukowicz, P., & Kuhn, J. (2020). Effects of augmented reality on learning and cognitive load in university physics laboratory courses. *Computers in Human Behavior*, *108*, 106316. https://doi.org/10.1016/j.chb.2020.106316

Weatherby, T., Wilhelm, T., Burde, J.-P., Beil, F., Kapp, S., Kuhn, J., & Thees, M. (2020). Visualisierungen bei Simulationen von einfachen Stromkreisen (translated as ‚Visualizations for simulatitions of simple circuits'). *Naturwissenschaftliche Kompetenzen in Der Gesellschaft von Morgen*, 1007–1010. https://www.gdcp-ev.de/wp-content/tb2020/TB2020_1007_Weatherby.pdf

Wilhelm, T., & Hopf, M. (2018). Schülervorstellungen zum elektrischen Stromkreis (translated as ‚ Students' conceptions on the electric circuit'). In H. Schecker, T. Wilhelm, M. Hopf, & R. Duit (Eds.), *Schülervorstellungen und Physikunterricht—Ein Lehrbuch für Studium, Referendariat und Unterrichtspraxis* (pp. 115–138). Springer Spektrum. https://doi.org/10.1007/978-3-662-57270-2

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41–49. https://doi.org/10.1016/j.compedu.2012.10.024

Zhang, H., Cui, Y., Shan, H., Qu, Z., Zhang, W., Tu, L., & Wang, Y. (2020). Hotspots and Trends of Virtual Reality, Augmented Reality and Mixed Reality in Education Field. *2020 6th International Conference of the Immersive Learning Research Network (ILRN)*, 215–219. https://doi.org/10.23919/iLRN47897.2020.9155170