Journal on Efficiency and Responsibility in Education and Science
ISSN: 1803-1617, doi: 10.7160/eriesj.2013.060403

PARAMETERS OF AUGMENTED REALITY AND ITS USE IN EDUCATION

Tomáš Jeřábek, Vladimír Rambousek,
Miloš Prokýšek
Charles university in Prague, Faculty of Education
jerab@gmail.com

Abstract

This article examines the issue of augmented reality and possibilities of its application in education. It briefly reports on selected results of a broader survey focused on technological, psychological, physiological and didactical aspects of the issue. It presumes that augmented reality has its unique place in technical teaching tools since it is a technological-perception concept, which in certain didactical situations creates more suitable perceptual environment than real environment itself on one hand, or virtual environment on the other. It focuses on identification of the technological-functional properties and specifics of augmented reality systems and on verification of model examples of augmented reality applications in school practice. It characterizes the course and results of empirical research project based on a descriptive case study exploring the cases of implementing selected application solutions of augmented reality into learning experience in accordance with the model of pro-active action research.

Key Words

Augmented reality, enhanced reality, mixed reality, augmented virtuality, education

ARTICLE INFO

Article type

Full research paper

doi: 10.7160/eriesj.2013.060403

Article history

Received: July 31, 2013
Received in revised form: October 9, 2013
Accepted: October 17, 2013
Available on-line: December 31, 2013

Introduction

The study on augmented reality and ways of its use in education arises from the needs of deeper notional and content definition of augmented reality in the context of education and at the same time it presumes that augmented reality can as an innovative didactical tool contribute to a more effective and better quality education activities through enhancing the system of didactic tools and their functions and become thus a suitable tool for supporting cognitive processes in various educational fields. This presumption is based on the properties of augmented reality, which owing to the combination of the real world with augmented information in various forms of their relation can increase informative value of the perceived, or mediated content and simultaneously provide various levels of mediality, or modality when transferring information through various perceptual channels with the use of suitable forms of interaction of the perceiver with the content.

It is possible to consider augmented reality (AR) a specific innovative technology or technologically induced perceptual environment based on the combination of perceived real environment and augmented, e.g. computer generated, elements (Milgram, 1994b). According to Johnson (2011), augmented reality is characterized by adding computer-generated context information layer into the real world, which leads to enhanced reality. Heim (1998) defines AR as overlapping basic visual field with computer-generated data.

Generally, we can characterize AR as a technology, which adds visual, sound and other virtual elements into the perceived reality, i.e. it makes use of the combination of real environment with intentionally introduced information, thus creating a new form of reality, which is information-richer than the original primary environment. This idea is realized through a number of ways, various technical devices and by its nature can function through all perceptual channels simultaneously or individually. Although AR is considered a technology, in a broader context it is a technological-perceptual idea, which involves a technological, perceptual and information aspects.

Alongside with the term augmented reality there are also other names and related terms in professional literature, e.g. enhanced reality, mixed reality or mediated reality. Terminology and definitions of these terms vary considerably depending on the authors and the context, in which they are mentioned. The term and definition variety of augmented reality indicates that there are a wide range of forms and technological-functional solutions of augmented reality taking on various shapes, goals and application, for which a deeper commonly shared definition is missing.

From the viewpoint of mutual definitions of the above mentioned terms, mainly classic Milgram's concept of virtual continuum (Milgram, 1994b) is interesting, through which he illustrates a degree and way of enhancing perceived real environment with augmented information. Within the virtual continuum, Milgram defines the area of mixed reality, enhanced reality and enhanced virtuality, by which he tries to interconnect these environments, or terms.

Besides Milgram's continuum of mixed reality, which separates enhanced reality from virtual reality, there is another significant view. Mann puts AR into the context of mediated reality. Within the taxonomy of mediated reality, in which Mann attempts to create an umbrella term for mixed, enhanced and virtual reality, he classifies virtual reality as a part of enhanced reality.

Elaborating the above mentioned definitions of AR and other related concepts, the following criteria, which should unambiguously distinguish enhanced reality from other technological-functional concepts, were defined. The systems of enhanced reality: 1. combine real environment surrounding the user with virtual elements, 2. are characterized by reactivity on real environment in real time (within the technological system of AR this is ensured by tracking system), 3. when adding (registering) virtual elements into perceived enhanced reality, they count on three-dimensional space of real environment.

Besides these basic technological conditions based on Azuma's criteria, there are other characteristics generally valid for related technological concepts, such as virtual reality. In this context we may say that augmented reality: 1. is created by means of a technical device, 2. is naturally immersive environment.

Technical devices ensure at least tracking, registration of virtual elements and their presentation, in some cases they mediate, or reconstruct real environment.

In the context of the term immersion in the area of virtual reality, augmented reality should be understood as non-immersive environment since AR technology does not seek primarily to persuade participants, or their senses that they are in „different reality". Immersive environment is however also described as environment, for which evoking the feeling of presence in the given environment is a determining parameter. The feeling of presence can be further divided into partial experiences: spatial, social or personal presence (Roussou, 2010). From this point of view, every environment of augmented reality is actually immersive because the participant is „left" (at least socially or personally) in this environment, which is only supplemented with certain data.

In an attempt to classify augmented reality systems more precisely, it is necessary to apply both the technological viewpoint based on the technical system and the resultant viewpoint characterizing the capabilities of the system through the properties of the realized AR, and finally users viewpoint, or perceptual.

From the technological standpoint, we may describe augmented reality systems through four parameters: The first parameter concerns the configuration of AR components, i.e. reality and virtuality.

By configurating AR components we mean a purely technical solution of their mediating towards the participant, or in which part of the presentation axis (real environment – technical device – user) the components are allocated from the viewpoint of the participant's perception. The following scheme shows the possibilities of location of these elements. It is partly based on Bimber's scheme of an image construction for augmented reality and Milgram's structure of visualising devices for mixed reality (refer to Figure 1).

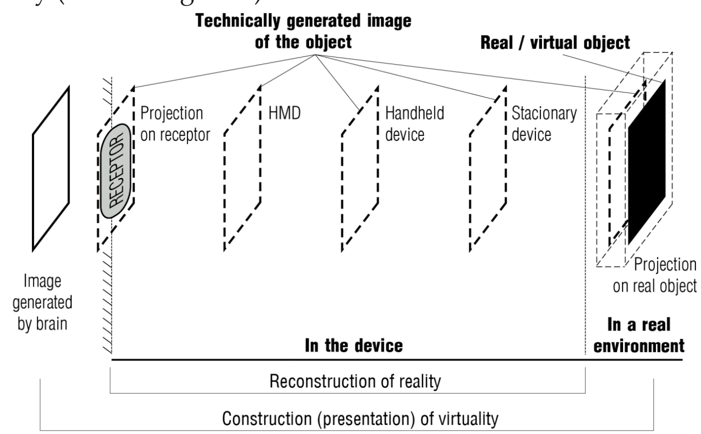

Figure 1: Ways of constructing an image of a virtual element and reconstruction of a real element (based on Bimber, 2006 and Milgram, 1994)

If we disregard extreme cases of presenting data behind the receptors, within a technological viewpoint we may define three basic conditions of a virtual and real element configuration (C1 – C3):

- C1 both elements are perceived directly (from real environment),
- C2 a real element is perceived directly, a virtual element through a technical device,
- C3 both elements are perceived through a technical device.

Systems within C1 configuration are characterised by merging a virtual element directly into a real environment. The resulting environment of augmented reality (both elements) can then be perceived by a user as integrated in terms of the location of both elements and with a higher degree of the feeling of a coherent environment. Mediating newly arisen augmented reality towards the user is not hence limited by a technical device, which would be necessary for its perception. A typical example could be e.g. projection on a real object or hologram. As for C2 configuration, where a real element is also perceived directly, but to perceive a virtual element we need a technical device, both elements are allocated separately. Solutions based on C2 configuration are for example systems with a head-up semi-permeable display or fixed systems with a semi-permeable mirror. As for C3 configuration, a technical device is necessary to perceive both elements. A real environment is then within these AR systems scanned and consequently reconstructed. These systems are most frequently and widely used (e.g. tablets or monitor-based systems), which reflects a fact that currently it is a technically simpler solution than in other cases.

When a real environment is mediated by a technical device (C3), AR system must meet a certain degree of quality of a scanned reality reconstruction. The issue of credibility and authenticity of a reproduced picture is described by e.g. Naimark. Unlike the other case when a virtual element is allocated in the device and reality is directly perceived, with visual systems a technical design of a semi-permeable display is the quality measurement from the viewpoint of the minimum disruption of perceiving a real environment and at the same time depicting virtual elements is sufficient quality.

The nature of control information constitutes the second parameter to describe AR systems from a technological standpoint. Control information is a necessary condition to meet the second fundamental AR system requirement, which is their reactivity on the changes of real environment in real time. Generally speaking, irrespective of the perception area targeted by augmented reality, the study defines the following three possible categories of control information (N1-N3):

- N1 real environment parameter,
- N2 intentionally-merged-into-the-environment artefact
  - simulation of a real element
  - fast-readable code,
- N3 user's parameter.

As for N1 group, control information is a naturally existing element, or its parameter present in a surrounding reality, to which the system reacts. It can actually be any parameter (shape, colour, sound frequency, coarseness of material, etc.) of real environment, or a combination of various parameters. In such case, the system is totally dependent on scanning and subsequent analysing of real environment. As for the mutual relation of the system and control information, user's position towards the system nor towards the control parameter is important. N2, the second category, has identical parameters.

It is actually a facilitation of the system within the process of the analysis of scanned real environment by means of merging such a type of artefact that is not significantly different from the surrounding environment and the identification of which is easier for AR systems. These artefacts can be of a various type, ranging from models similar to real objects to a pure form of a code (e.g. QR code or barcode). The form of the artefact itself is more or less irrelevant from the viewpoint of the nature of control information. When scrutinizing the variability of control information within this group we may define two sub-groups: (a) artefacts imitating real elements and (b) „codes", i.e. artefacts that are easy to recognize because they differ from common elements of real environment. In N3, the third group, a close bond between user and control information is typical. It is usually information about a user's quality or technical device as a part of AR system held by the user. This information is usually of a geophysical, biophysical or physical character (position, temperature, speed, etc.) whereas nowadays it is a combination of GPS technology, compass and accelerometer, which is most often used to get information about user's position and orientation.

The third parameter to describe AR systems from a technological viewpoint is the number of users, for whom the AR system is intended, in other words how many users can share the system simultaneously and perceive resulting reality. This criterion takes this purely technical solution into account, functions of AR system as a technical device to aim the content of enhanced reality at the number of participating users irrespective of the purpose of use. AR system can provide the effect of enhanced reality to one user only or to a bigger group of users. Within a bigger group, the system can fully provide a required effect either to all users identically or to a smaller part of the group only and for the remaining users augmented reality is limited in a certain way. The systems can be hence divided into three categories according to the number of users (U1-U3):

- U1 single-user systems,
- U2 limited multi-user systems,
- U3 multi-user systems.

A possible number of participating users usually depends on the presentation element of AR system, which based on its technological solution and expected location towards user's receptors presents AR content to the given number of users.

The last parameter of a technological viewpoint is the support of interaction between user and system. By the support of interaction we understand an opportunity for the user to interfere with certain commands (gestures, sound commands, through a technical device, etc.) with the construction of enhanced reality, most frequently it is about influencing the form and amount of virtual elements. By interaction we do not mean e.g. starting the device, change of position or a complete change of control information. It is interference in otherwise automatically running application of the system, which alters the course of the algorithm. In this connection there are two basic situations that AR system can appear in:

- I1 supports interaction,
- I2: does not support interaction.

From the resulting standpoint, we may describe the systems of enhanced reality by means of three objective and two subjective parameters from the AR user's viewpoint. The first parameter comprises a ratio of real and virtual component of AR in terms of Milgram virtual continuum. The parameter aims to cover not only the ratio of the amount of individual components, but also the nature of the environment, which is the primary source of information. Augmented reality on one side and augmented virtuality on the other side can be considered the poles of this continuum. The second objective parameter concerns information density of mediated AR, or the ability of the system to provide a user with information in low or high density. The last, third parameter is the purpose of AR realisation in terms of the relation of augmented information to original reality. Thus we can distinguish modified reality (e.g. „by taking away" information), augmented reality (e.g. adding existing but for the user inaccessible element), or enhanced reality (adding non-existing element) when the original environment is enhanced with information. Among subjective parameters, we may include a degree of authenticity of the resulting AR and the feeling of participation in AR when the user of enhanced reality can be a participant at the same time and becomes thus a part of AR or he or she is only an observer of arising AR.

From the perceptual standpoint, we can primarily assess the ability of the system to work with individual perceptual channels, i.e. to generate information such as visual, auditive, tactile, or olfactoric. Defining the structure of perceptual standpoints and identifying differences in AR systems are primarily based on a functional principle of human sensory organs, or on biophysical functions of the receptors. In this context, (1) localization and the effect of stimulus and (2) a type of energy affecting the receptors are primarily significant. Augmented reality (unlike virtual reality) requires the user to perceive all perceptions of generated virtual elements in the context of surrounding environment and correctly localized towards real environment. AR systems, or concrete applications must therefore take this aspect into consideration. With sensory organs with telereceptors, AR system can merge virtual elements (the sources of the stimuli for sensory organs) more or less wherever into real environment so that the resulting interpretation of the stimuli would make the user believe that the virtual object is merged concretely into surrounding environment.

The parameters defining the nature of the added information differ based on the type of the perceptual channel, with which the system is working, Even though augmented reality, by its nature, can be realized through all perceptual channels, this added information is in vast majority visual. This type of added information can be described by means of three parameters. The first parameter is the type of information, which can be a text, symbol, graphics, or realistic visualization. The dynamics of visualisation can be considered another parameter. Augmented visual information can take form of static, cartooned or dynamic visualisation. Spaciality is the last parameter. Added visual information can be viewed two-dimensionally (2D), or the system allows work with three dimensions and visualise objects as 3D. Far more often the system only supports monocular hints of perceiving spatial depth, so we are dealing with pseudo-spatial visualization referred to as 2.5D (Oh et al., 2011; Prokýšek and Rambousek, 2012).

Material and Methods

Following technical research in the field of augmented reality undergoing mainly in the nineties of the last century (e.g. Azuma, 1997), application oriented surveys in the field of psychology and education (e.g. Bajura, 1992; Bottecchia, 2010; Botella, 2010; Hughes, 2009) have appeared. Due to financial and technical requirements of augmented reality systems, the survey were mostly carried out in laboratory conditions and their outcomes did not reach educational practice. The development of new technologies, mainly portable mobile devices providing a relatively good quality scanning, recording and viewing apparatus and being comparatively affordable, brings new perspective to the use of augmented reality systems and applications in education, or a real possibility of implementing these systems into school practice. This presumption is also supported by the experts of Horizon Report, a futurology study, according to which augmented reality is about to play a key role in technologies and work with information in coming years (Johnson, 2011).

The study on augmented reality and ways of embedding augmented reality in education, on which this paper is based, sought to examine this issue from the technological, psychological, physiological and didactical points of view. Primarily, it deals with the description of technological-functional properties and specifics of augmented reality, specifications of the significance of combining real environment with added information for information value of the provided content, identifying methodology of augmented reality, defining the system of criteria for technology solutions and didactical use of augmented reality and generating didactical aspects of augmented reality in education.

The study presumes that augmented reality has its unique place in technology teaching tools because it is a technological-perceptual idea at times creating more conducive perceptual environment than real environment on one hand, or virtual environment on the other.

Empirical research into didactical use of augmented reality, consisting of three separate parts, was an important section of the study. The first part provides a qualitative questionnaire survey among experts from the field of development, history and application of augmented reality with the aim to obtain relevant data from a technological and functional point of view and on the use, benefits and aims of augmented reality in education. The subjects were 44 mainly international experts. Considering the focus of the questionnaire, two open questions were suggested, the first of which was aimed at the expected technological and functional development of augmented reality, the other at finding out the opinions on using augmented reality in education. The questionnaire was supplemented by qualitative interviews with selected respondents carried out through a video conference seeking to gain more detailed and concrete respondents' views.

The second part of the empirical research comprised a qualitative questionnaire survey among practicing teachers, which focused mainly on embedding augmented reality in education. The subjects were practising primary and secondary school teachers (ISCED 1, 2 a 3) with a various subject orientation. 173 respondents took part in this survey.

Both surveys aimed to gain thought-provoking information on typical examples of application solutions in education, functional possibilities and potential of augmented reality, or defining didactical situations suitable for the parameters and didactical specifications of augmented reality (Jeřábek, Prokýšek, Rambousek, 2013).

The outcomes of this part of the survey allowed to form the third part, an empirical research project, seeking to contribute to the above mentioned presumption. The research project was based on a descriptive case study examining typical examples of implementing selected application solutions of augmented reality into learning and teaching practice in the context of relevant thematic units. The solutions were implemented by means of the model of pro-active action research initiated by a researcher and carried out by a teacher with a researcher's technical support. The research was conducted in the selected primary school class, namely in the 7th grade of primary school

(ISCED 2), with 25 pupils aged 12 and 13 during one school term. Its subjects were pupils and a teacher of the selected class. The teacher, selected on the basis of defined parameters following up the findings of the first two research methods and working hypotheses, taught in the selected class throughout the whole research.

Within the action research various application solutions of augmented reality, formulated on the basis of the ideas obtained from the above mentioned questionnaire surveys taking on board the teacher's educational aims, were applied. These solutions also corresponded to the technological, resultant and perceptual viewpoints defined in the previous part of the study. The choice of concrete application and technical solutions was subject to the availability of devices and financial resources of the schools and educational institutions with a two to three years' perspective. Based on the given parameters, tablets with 7.0“ WSVGA displays equipped with a front and rear camera and GPS were selected as a technical solution. For some application solutions, 12“ laptops equipped with a webcam were used, meeting almost the same requirements as the tablets.

From the technological point of view, augmented reality systems were multi-users on a limited basis. They provided allocation of both components of augmented reality inside the technical device and allowed for the interaction between the user and the system. Within the research project, 10 application solutions were applied representing more or less various type groups from the perceptual (in the visual field) and resultant point of view.

Recognizing was an application type group of the first applied solution. It made pupils familiar with various types of a Medieval knights' armour from various European countries. The aim of the application was for the pupils to learn to match basic types of a knight's armour with a concrete country and time period. The element of real environment, the user's face, was the control information for the system. Application solution was of a magic mirror type and the augmented information took form of static or animated 2.5D objects. The system after detecting the user's face through visualisation of the generated object on the required coordinating axes in the picture „dressed up“ the user into the part of knight's armour from their shoulders up. The users could touch themselves (click on themselves in the case of laptop) to find out more information about the knight's armour.

Another application solution was focused on reinforcement of taught material. It was part of a historical walk in the form of a competition. The technical solution comprised only tablets using GPS, a rear camera and Wi-Fi connection. The pupils were to walk through concrete areas defined by GPS coordinates, where the system made a question or task available for the given area including supporting multimedia information (description of an object in the neighbourhood, a short text, video etc.). This case of implementation required easy mobility of the system and allowed for work in small groups (e.g. 2-3 pupils sharing 1 device). In this case, the system worked in the visualisation mode on the axis of scanning with control parameters of GPS coordinates and user's or device position. Through the device, pupils were first looking at the surrounding reality as one unit, into which text and photo information about the objects located in a concrete direction and distance from the user were added. In addition, the system used the analysis of the surrounding picture when completing the task in a concrete location. The interactivity between the user and the system was very high.

Another example of implementing augmented reality into the teaching and learning process concerned an interactive application focused on pupils' creative art activity. The task was to create a picture inspired by Arcimboldo's specific style of painting. Pupils were creating a collage face or bust by moving objects representing various types of fruit. The technical solution of the application was similar to the first example above, however the course of the activity and didactical aim were different. User's visualised face represented a canvas, on which the final picture was created. In terms of augmented information, the user perceived the picture as spatial because of 2.5D static graphics (it changed its position and rotation according to the position of the face), the system thus allowed for a composition in Y axis as well.

The case study primarily focused on implementing the augmented reality and on the participants' attitudes to this phenomenon, mainly on the teacher's feedback on implementing augmented reality into education and her opinion on a concrete application solution. With pupils, it focused on their evaluation of and attitudes to augmented reality application.

The basic methods used for collecting data for the case study were participating observations, partially structured interview with the teacher, structured interviews with pupils, analysis of pupils'portfolios and preference questionnaires distributed after each lesson with augmented reality application (Fuglík, 2012). The preference questionnaires monitored pupils opinions on the difficulty of the application, interest aroused by the application and, above all, on the preference of further use of augmented reality in the class.

Questions in questionnaire were designed using Lickert scale (Chráska, 2007). Responses were transferred into numeric values for statistical analysis needs (see Table 1). Furthermore numeric data were aggregated using arithmetic means for interpretation.

Results

Within the preference questionnaire survey, a total of 221 questionnaires in 10 sets were gathered (Q1 – Q10). Evaluation scales were transferred into interval of 1 to 5, see Table 1.

	1	2	3	4	5
q1	Very easy	Easy	Standard	Complicated	Very complicated
q2	Very interesting	Interesting	Standard	Boring	Very boring
q3	Learning definitely	More learning than play	I don't know	More play than learning	Play definitely
q4	Absolutely Yes	Almost Yes	I don't know	Almost No	Definitely No

Table 1: Numerical Interval of Preference Questionnaire Evaluation Scale

Chart (Figure 2) comparing an average score of the particular applications shows that pupils found the applications easy to use (q1).

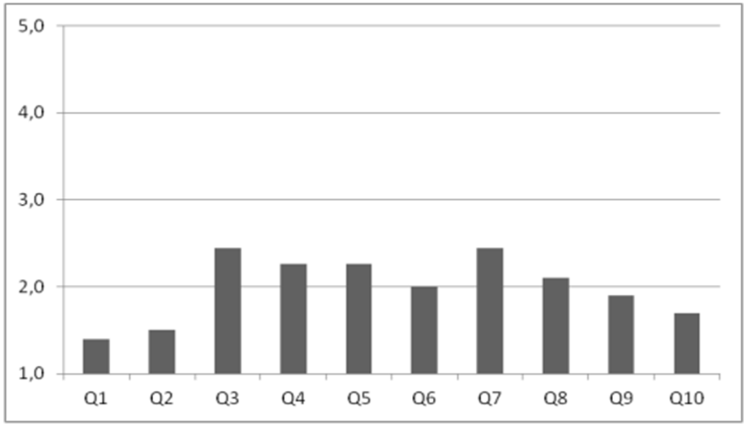

Figure 2: Average Evaluation of Q1

Chart (Figure 3) compares answers to questions q2, q3 and q4. As is obvious from the data, at the beginning of the survey pupils perceived AR as positive. At the beginning of the research, pupils perceive AR application more like play than a learning tool (see Tab 1 – rating the answers). At the same time they express a very positive attitude to further use of AR in learning. This situation may be caused by the novelty phenomenon of AR in learning. Pupils are captivated by a new learning tool, by a new way of learning.

The next expositions show that q2 and q4 lines converge to line q3 as expected. Pupils stop perceiving AR as a new element and their ratings get closer to a neutral opinion. Nevertheless, they still welcome the use of AR in the lesson and find it interesting.

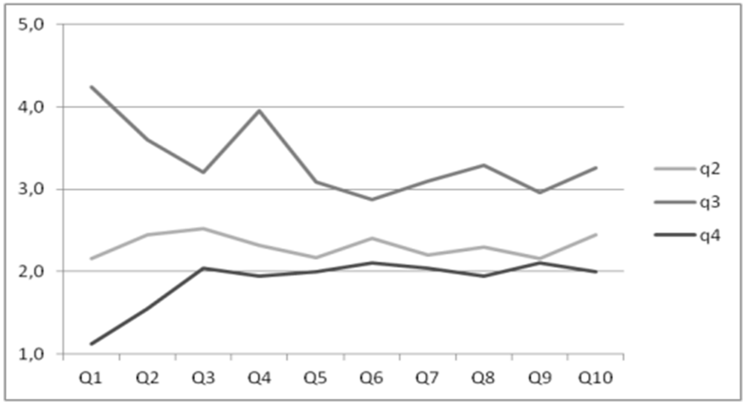

Figure 3: Average scores of Q2, Q3, and Q4

Trend line q3 shows a divergence of the otherwise obvious trend. This divergence (Q4, q3) may have been caused by the selected teaching technique and the application type. Exposition was carried out within outdoor project-based learning. This form of learning is not common for pupils and it may have influenced their rating of AR application.

Question q1 focuses on a particular AR application and not on the pupils' attitude to AR as a teaching method. It does not show the same trend as with q2 to q4. Statistically significant is the correlation of questions q3 and q4 (-0.82 on the level of $p=0.05$). This correlation indicates that preferences for using AR for further learning is related to perceiving the application solution as play.

The interviews with pupils confirmed the interpretation of the findings of the preference questionnaires. With the growing pupils' experience of AR and a frequent use of AR in the learning process, pupils start to feel the importance of AR for learning, yet their preference for further use of AR remains practically unchanged.

Within a partially final structured interview, a teacher mainly emphasized the importance of the combination of augmented information and a real element for the graphicness of the learning content. She also stated that she takes AR as an opportunity to enhance her portfolio of teaching methods. The application solutions met her expectations in terms of the pupils' abilities to handle and quickly master the devices and applications, as well as in terms of the didactical-technical aspects of the applications. Further she confirmed the findings gained within the observations that occasional technical problems (e.g. application crash and necessity to run the application again or imperfections in recognizing the faces in the picture) did not demotivate the participants nor disturb the learning process.

Discussion

Empirical research realized in this study on augmented reality consisted of three separate parts, which were focused on different parameters of AR and its use in education. The character of sample of respondents for each of the three parts of research was so different too. The first survey involved 44 mainly international experts. The second survey involved 173 teachers. Despite the relatively small number of respondents in the first part of the research, the results can be seen in a wider context, because the sample of respondents consisted of experts in the field of AR. The outcomes of both surveys have come up with thought-provoking information on typical examples of application solutions in education, functional possibilities and potential of augmented reality, or defining didactical situations suitable for the parameters and didactical specifications of augmented reality and allowed to form the third part, an empirical research project.

Empirical research project involved 25 pupils and one teacher. Due to the predominantly qualitative method of data collection and due to the character of realized study can be research sample considered as a sufficient sample to draw the above conclusions. At the beginning of the research, pupils express a very positive attitude to further use of AR in learning that may be caused by the novelty phenomenon of AR in learning. Further, pupils still welcome the use of AR in the lesson and find it interesting. Here we may conclude that the novelty phenomenon was substituted by the factor of didactical specifics, in other words by the characteristics of the teaching method.

The influence of the researcher on the characteristics of the research situation was mitigated by the presence of the researcher in the classroom even before the actual start of the project in the phase of familiarization with the given technology. Compensation of effect of novelty and Hawthorne effect was also achieved length of case studies. During this time the deployed technology and the presence of the researcher becomes essentially unremarkable. The results of the case study are consistent with the assumptions of researchers and come up with interesting conclusions regarding the use of AR in education, especially for the practical deployment of AR in the school environment. The results are also consistent with the similar conclusions of the other studies focused on the use of AR in education (e.g. Liarokapis, 2002; Domes, 2007; Dunleavy, 2013), which stress the characteristics of AR, like real-time augmented presentation, visualization of the complex phenomena, low-cost,interactive interface, etc. Nevertheless, these results cannot be generalized, as they were the cases examined in the specific action research.

Conclusion

Based on the working hypotheses and research findings we may conclude that augmented reality represents a specific category of teaching tools, for which we can define a system of technological-functional, perceptual and resultant criteria as this paper suggests. Further we may conclude that the research project confirmed the hypothesis that there are didactical situations, for which AR creates effective perceptual environment. The teacher within the empirical study finds AR beneficial for the learning process, mainly for motivation, graphicness and information value of learning content.

The findings of the empirical study certainly cannot be generalized. The research project is to be seen as a pilot project suggesting a case study with the findings applicable only to the environment of the research sample and with the use of the particular device. It was confirmed though that along with the currently available school devices it is feasible to realize a wide range of AR application solutions having an effective impact on learning. It was also confirmed that even though teachers are not overly familiar with augmented reality, they are able to find concrete didactical situations for which they find the use of AR highly beneficial.

Acknowledgements

This work was supported by grants of the Czech Science Foundation P407-12-1541 Information Technology Competencies of Children and their Development in Primary and Lower Secondary Schools.

References

Azuma, R., T. (1997). 'A Survey of Augmented Reality'. In *Presence: Teleoperators and Virtual Environments* 6, August 1997. [Online], Available: http://www.cs.unc.edu/~azuma/ARpresence.pdf. [2013-07-22].

Bajura, M. (1992). 'Merging Virtual Objects with the Real World: Seeing Ultrasound Imagery within the Patient'. In *SIGGRAPH '92, Computer Graphics*, 26, 2, 1992, [Online], Available: http://cs.iupui.edu/~tuceryan/pdf-repository/bajura-siggraph-92.pdf. [2013-07-12].

Bimber, O. and Raskar, R. (2006). '*Modern Approaches to Augmented Reality*. Mitsubishi Electric Research Laboratories, [Online], Available: http://www.merl.com/papers/docs/TR2006-105.pdf [2013-10-1].

Botella, Ch. (2010). 'Treating Cockroach Phobia With Augmented Reality'. In *Behavior Therapy*, 41 (3), 2010, str. 401-413.

Bottecchia, S. (2010). Augmented Reality System for Collaborative Tele-Assistance in the Field of Maintenance through Internet'. In *Augmented Human Conference*. April 2–3, 2010, Megève.

Chráska, M. (2007) *Metody pedagogického výzkumu : Základy kvantitativního výzkumu*. Praha : Grada Publishing, a. s., ISBN 978-80-247-1369-4.

Domes, N. (2007). Entwicklung eines Augmented reality Systems fur die Schulchemie (exam work, Johannes Gutenberg University Mainz, 2007)

Dunleavy, M., and Dede, C. (2013). *'Augmented reality teaching and learning'*. In M.J. Bishop & J. Elen (Eds.), *Handbook of Research on Educational Communications and Technology*. 4th edition, Volume 2. New York: Macmillan.

ISSN: 1803-1617, doi: 10.7160/eriesj.2013.060403

Fuglík, V. and Černochová, M. (2012). 'Research Findings on Implementing Student Portfolios into Teacher Education'. In: In *9th International Conference on Efficiency and Responsibility in Education (ERIE 2012)*, Praha: Czech University of Life Sciences Prague, pp. 130-139.

Heim, M. (1998). '*Virtual Realism*'. New York: Oxford University Press, p. 210.

Hughes, Ch., E. (2005) 'Mixed Reality in Education, Entertainment, and Training'. In *Moving Mixed Reality into the Real World*, 2005, pp. 24-30.

Jeřábek, T., Prokýšek, M., Rambousek, V., (2013). 'Using augmented reality in education'. In Efficiency and Responsibility in Education 2013. Praha: Czech University of Life Sciences Prague, pp. 256 263.

Johnson, L. (2011). '*The 2011 Horizon Report*'. Austin, Texas: The New Media Consortium.

Liarokapis, F. et al (2002). 'Multimedia Augmented Reality Interface for E-learning (MARIE)'. In World Transactions on Engineering and Technology Education, Vol.1, No.2, 2002. pp. 173-176

Milgram, P. (1994). 'A taxonomy of mixed reality visual displays'. In *IEICE Transactions on Information Systems*, Vol. E77-D, No.12 December 1994. [Online], Available: http://www.eecs.ucf.edu/~cwingrav/teaching/ids6713_sprg2010/assets/Milgram_IEICE_1994.pdf. [2013-07-19].

Milgram, P. (1994). 'Augmented Reality: A class of displays on the reality-virtuality continuum'. In *Telemanipulator and Telepresence Technologies*, Vol. 2351 Bellingham, [Online], Available: http://wiki.commres.org/pds/Project_7eNrf2010/_5.pdf. [2013-07-10].

Oh, K. E. et al (2011). 'Which properties in 3D visualizations cause comprehension difficulties?' *Proceedings of the American Society for Information Science and Technology*, vol. 48, no. 1, pp. 1-4.

Prokýšek, M. and Rambousek, V. (2012). 'Efficiency of the application of spatial visualization in instruction in relation to spatial intelligence'. In *9th International Conference on Efficiency and Responsibility in Education (ERIE 2012)*, Praha: Czech University of Life Sciences Prague, pp. 481-488.

Roussou, M. (2010). '*Immersive Interactive Virtual Reality and Informal Education. Proceedings of User Interfaces for All:Interactive Learning Environments for Children*'. Athens, February 2000, [Online], Available: http://www.ui4all.gr/i3SD2000/Roussou.PDF. [2013-07-14].