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Augmented reality impact in the development of formal thinking

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Abstract. Experiential activities in classrooms and their repercussions in the process of building senses (or meanings) are of great value for the cognitive development of students. In this perspective, this paper presents the making of a virtual and augmented laboratory prototype in which the objective is to contribute in the process of helping physics students develop formal thinking, through the demonstration of invisible occurrences and situations that involve natural phenomena, as well as allowing the interaction with multimedia resources and educational objects. Therefore, discussions about the potential of virtual laboratories and augmented multimedia resources as technologies capable of aiding in the cognitive development of physics students will be exposed along this article.

Keywords: education; formal thinking; virtual reality; augmented reality; STEM;

1 Introduction

Teaching and learning physics is a hard task, as is reported in innumerous works. Teachers do not always have the conditions to offer practical activities due to the lack of laboratories in schools and, additionally, several experiments are not capable of completely exposing the natural behaviors that are happening once that certain phenomena are not visible to the human eye (such as electricity, magnetism, heat, etc). Som can even entail environmental or personal hazard (such as radioactivity) and, thus, cannot or should not be done without the proper security measures, which prevents them from being performed in most schools and even some universities.

The hardship in teaching and learning physics, particularly in electricity related subjects, can also be explained by the absence of formal thinking in teenagers, as a consequence of failing to evolve from the concrete thinking of a child to the formal thinking of a teenager, such as is described by Inhelder and Piaget [1]. According to the constructivist theory, knowledge is neither in the objects nor in the people but it derives from the action of people over the objects. Considering that the evolution of thought could be delayed or anticipated in consequence of the conditions in the context in which children and teenagers find themselves, it is desirable to investigate whether creating the opportunity to perform experiments in virtual labs could entice conditions to accelerate the formation of formal thinking, necessary to the physics learning. Inhelder and

adfa, p. 1, 2011.

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Piaget [2] describe three formation stages of formal thinking:

- Stage I (until 7 to 8 years of age) – subjects' attentions are aimed at the triumph or failure without considering its mechanism. The subject acts only to reach the objective and does not ask itself how it is done.
- Stage II (from 7 to 9 until 11 to 12 years of age) – the beginning of concrete operations. Subjects are limited to a "reading" of the facts, which is now exact since it is organized through concrete operations of serializing and correspondence, however, they do not look for a reason for these facts through formal operations of implication and others, which is characteristic of the hypothetical-deductive thinking.
- Stage III - Formal stage – The final phase, preparatory to adult thinking, takes place between twelve and fifteen years and involves the appearance of formal as opposed to concrete operations. Its most important features are the development of the ability to use hypothetical reasoning based on a logic of all possible combinations and to perform controlled experimentation.

Under certain conditions, an acceleration in the cognitive development would be possible minding some general principles that can be found on the basis of each one of the learning process of an individual:

- Subject activity: A genetic theory implies that the cognitive development is made essentially by the interaction between the subject and the world that involves it. A situation of apprenticeship is as more productive as the subject is more active. Thus, practical learning opportunities are valuable for the cognitive development.
- Scheme coordination: A second principle is that during the cognitive evolution demonstrated by the transversal studies, the knowledge progress can be defined by the fact that every new structure integrates the previous schemes, coordinating them. The experiential activities and their observable elements are not sufficient to provoke an authentic thought progress while they are not inserted in an inference system that allows the chained processing of the successive stages of the observations provoked by the different phases of experiencing.
- Evolution stages: offsets of some wingspan were frequently noticed in several studies undertaken in different cultural environments. Lateness or precocity may be explained by the degree of solicitation exercised by the environment of general cognitive elaboration; sometimes it is sufficient to place a problem to unleash mental processes already present in an underlying manner, even though they are not requested in the everyday task. In laboratory environments, it is possible to create the conditions necessary for this to occur.

As a consequence of this, the science, technology engineering and mathematics (STEM) education has supported itself in the practical and experiential use of real laboratories. As was highlighted by Klahr, Triona & Williams [3], hands-on science promotes learning because it is consistent with the concrete-to-abstract nature of cognitive development, because it provides additional sources of brain activation via kinesthetic involvement, and because its intrinsic interest increases motivation and engagement.

With current technologies, new approaches came to support the process of cognitive

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development. On this view, Scalise et al. [4] indicate that many of today's students experience a portion of their scientific study through virtual labs and simulations, experiments and demonstrations of scientific phenomena delivered up via computer software. "Students may flourish in the traditional science-lab setting, intrigued and motivated by the tools, the sights and smells, and the surprising (and sometimes impressively startling) outcomes of experimentation, but they may also be adept at and drawn to emerging technologies, thriving in a virtual setting, with its visual cues, instant feedback, and self-pacing options for repeating a unit or moving quickly ahead" [4].

However, in many cases, the experiments require an abstraction level still not fully reached by all students in formation. Such a level is known as the formal operational stage and it begins at approximately age twelve and lasts into adulthood. As adolescents enter this stage, they gain the ability to think in an abstract manner by manipulating ideas in their head, without any dependence on concrete manipulation [4].

Several types of research have converged to promote learning through practices, aiming at building knowledge through realization, thinking, testing and exploration. In a broader sense, the active learning has been seen as a relevant teaching method for learners to develop critical skills and knowledge. This is especially relevant to STEM education and engineering courses that have to prepare future professionals for solving problems that could not be anticipated, what requires experiments to bring a proper solution. The experiential learning emerges as an important element for the approach discussed in this article, which involves augmented reality (AR) resources to promote learning through the understanding of experience and its transformation into knowledge.

The virtual labs have been receiving attention regarding the development of educational solutions using augmented reality due to its ever-growing use in the educational scope at a global level, according to the New Media Consortium (NMC) report [5], which identifies and describes the trends, challenges and the developments in technology that may impact the technological planning and decision making in world education. According to that report, regarding higher education, the technologies and practices that will most likely be in use in its areas for the next 5 years were highlighted. Among them, the intensification of the development of AR technologies was pointed out, accompanied by the comeback of mobile learning to the educational scene starting at 2017.

As far as the cognitive development of students, Gruber et al. [6] claim that, in a pedagogical point of view, experimental activities provided by AR encourage the construction of mental models based on the practical observations of the concepts and principles involved, creating the connection between theory and reality, especially in topics that involve natural and technological sciences. Besides that, the more these activities incite the resolution of practical problems, the better qualified will be the learning of these students, since they enrich and solidify their theoretical knowledge.

Facing such assertions, this paper aspires to expose the implementation of a Virtual and Augmented Physics Laboratory. Its goal is to supply the development of formal thinking through interactive experiences of physics phenomena, which involve the interactive use of three-dimensional objects, animations, and simulations, as well as other educational media that aim to stimulate the active interaction of students in a similar manner to hands-on experiments done in real labs.

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2 Augmented reality in education

AR is the integration of multimedia resources with physical elements of the real world. In this integration, computer-generated graphical elements are presented in the user's technological device, simultaneously with the real environment elements. This way, it is possible to transform the user's surroundings. According to Milgram and Kishino [7], AR is composed of a real environment "augmented" by the means of virtual objects.

AR features expand users' channels of interaction with educational content and attract greater learning opportunities. Other benefits enabled by AR consist in the reach of more elevated levels of motivation and engagement by the users, the 3D visualization of virtual objects interposed with real ones and the scale visualization of phenomena that are not perceptible in the real world through different perspectives or angles. These characteristics aid the users in assimilating abstract and complex concepts, easing the comprehension of a determined educational content (Chang et al. [8]; Furió et al. [9]). Besides that, AR gives support to the comprehension of complex phenomena, providing unique visual and interactive experiences, which combine real and virtual information, helping to explain abstract concepts to students [11].

Still in relation to the pedagogical potential, AR can present multimedia resources with the possibility of different levels of observation (zooming, rotating and translating), transforming the traditional didactic resources, which in many cases impose an elevated cognitive charge in students, overloading their cognitive structures and eventually compromising their performance and cognitive development [12]. The AR approach allows them to observe objects of study through several angles turning explicit certain visions, that help them to comprehend the behaviors of such objects, especially when part of that behavior is explained by invisible characteristics, such as a magnetic field making a coin and a magnet attract each other. AR also allows placing an object of study under conditions that possibly would not be feasible to reproduce in the real world and observe its behavior, which would ease the perception of more generic behavior rules and, therefore, abstractions in the behavior of the observed phenomenon.

3 Advantages of augmented reality for educational ends

In relation to the advantages offered by the multimedia resources developed in AR, some characteristics considered relevant and that promote a broad acceptance of the use of these virtual environments for educational ends are: a) low cost, since investments are limited to technological development, the costs of buying several pieces of lab equipment and maintaining them are cut, as well as hiring the professionals to manage the practical activities; b) no risk to the safety and health of users, once that, contrary to real laboratories, students only interact with simulations, thus never get into contact with hazardous material, e.g. toxic gas, radiation, and electricity, that may harm them; c) user actions do not create environmental harm, instead of what may occur in real environments, in which a certain experiment may use a great amount of energy or could produce dangerous residue that may damage the environment (Gonzalez-Pardo, Rosa et Camacho [13]; Potkonjak et al. [14]; Herpich et al. [15]).

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It is possible to verify that the benefits offered by the AR multimedia elements go beyond that enable the student visualization of the reality with traditional media, e.g. videos, 3D objects, simulations, etc. It also allows the creation of context, which in the traditional ways would not be possible by several reasons, for example: AR enables the demonstration of invisible occurrences in microscopic situations in which would be impossible to view the structures of a certain element (e.g. atoms and electrons); situations that involve a natural phenomenon, such as the electric or the magnetic field; the presentation of dynamic behaviors that vary in function of one or more parameters, which hardens the plain observation for being either too slow (e.g. the atomic decay and the erosion caused by a river) or too fast (e.g. free falling objects and mechanic collisions); the exposure of internal structures that cannot be revealed without affecting the execution of a determined experience (e.g. the human respiratory system or the functioning of a heart); the simple easiness of configuring parameters in order to modify the experiment, allowing the repetition and reversion of the processes being exhibited.

Besides offering a vast array of multimedia resources, AR also presents the portability between different technological devices. In the educational area, AR has presented relevant advances, demonstrating its capacity of contributing effectively to the teaching and learning processes in many diverse areas of study, e.g. electricity [15], fluid dynamics [16], electromagnetism [17], among other areas. The capacity of using multimedia resources consists in an inherent advantage to the AR technologies, since it allows the student to interact with videos, animations and many other possibilities. This perspective encourages the multimedia learning, which constitutes by itself in a benefit in the pedagogical point of view because, according to Mayer [18], people learn better with words and images than with words alone. The author emphasizes the importance associated with the methods for projecting multimedia instructions, with the intention of improving the student's comprehension of the presented material.

4 Virtual Learning and Remote Academic Work Environment

The Virtual and Augmented Laboratory integrates the development of two modules of the AVATAR (the portuguese acronym for Virtual Learning and Remote Academic Work Environment) project [19], which has the main goal to implement ways of enabling the learning of physics by the means of a virtual lab, built in the Open Simulator platform and of a mobile AR application, developed using the Unity platform and the Vuforia framework. To accomplish this, it congregates the use of many diverse technologies that make feasible the access of its users to interactive and engaging simulations, besides innumerous didactic contents, among other pedagogical resources, with the intent to promote the development of STEM areas.

Regarding the development of formal thinking, as was established by Piaget [20], there are four periods in the evolutionary process of the human species: the sensorimotor stage (ages 0 to 2), the pre-operational stage (ages 2 to 7), the concrete operational stage (ages 7 to 11 or 12) and the formal operational stage (ages 12 and beyond). The starting and ending ages for these stages may present variations according to the characteristics of each individual and the richness (or lack thereof) of the stimuli provided

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by the environment in which the individual is inserted. Under the STEM education perspective, the theory elaborated by Piaget [21], the period involving concrete operations specifically talks about an important aspect that refers to the development of the capacity of an individual to interiorize actions. In other words, the apprentice begins to make mental operations and no longer relies only on physical actions typical of the sensorimotor intelligence. For example, if asked what is the size of a certain object, between many, the apprentice will be able to answer correctly by comparing them using a mental action, i.e., without the need to measure them with a physical action.

In the virtual and augmented labs, the student has at hand experiments capable of enticing the development of operations typical of the formal thinking (identity, negation, reciprocity and correlation) or of the higher order thinking, which allows the exploration of variables in the behavior of the experiments, aiming at the intuition of general rules that summarize the functioning of the observed processes. Students usually present difficulties in selecting the correct variables to study the consequences of their modifications. It is also hard for them to formulate hypothesis capable of being tested and, sometimes, cannot come to the right conclusions about the experiments. There is a need to offer a scaffold, a cognitive tool that can aid them to settle these issues and to propose effective and efficient learning situations.

The environments supported by technology can integrate these cognitive tools with the simulations of a virtual laboratory. This would ease the performance of the experiments with varying contour conditions and process reversibility, which would enable different results to be obtained, observed and compared, besides letting them list which elements effectively influence the results. This cannot always be done in a real context, but it can be built in a virtual scenery. In the following sections, each of the two modules of the project AVATAR will be described and presented in better detail.

4.1 Virtual Physics Laboratory

The AVATAR project is composed of educational resources capable of assisting students in the process of learning content related to the laws of physics and the phenomena and processes that occur in nature that relate to the physics principles. In order to build the virtual lab, the use of virtual worlds like the Open Simulator was adopted, which enabled the development of three-dimensional sceneries, interactive simulations and the insertion of several pedagogical objects that can demonstrate to students the occurrence of phenomena and the physics concepts to which they are entailed.

In the virtual laboratory, students are represented by avatars, an aspect that lets them play the role of a character and feel immersed in the virtual environment during their interaction with the learning objects disposed of there. Regarding the educational resources to which the students may interact during their navigation in the virtual lab, several experiments were developed with the intent of exposing the event of physics phenomena in day-to-day situations, as well as in situations found in real physics labs. As to involve students with the inherent educational aspect of the experiments interactive sceneries was built, allowing the user change the experiments, running variables, offering constant feedbacks and allowing them to observe in a clear manner the gains that the simulations can offer to their instructive formation.

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4.2 Augmented Mobile Physics Laboratory

In order to reach a bigger number of users and become broadly available in different platforms, project AVATAR was developed in two distinct modules, the first focus in the use of personal computers as a way to let students access the virtual lab previously presented. The second module, however, encompasses the use of mobile devices. Concerning this module, Figure 1 presents the architecture diagram for the augmented mobile lab, which demonstrates the most relevant actions that students can perform during the use of the mobile device application with AR resources.

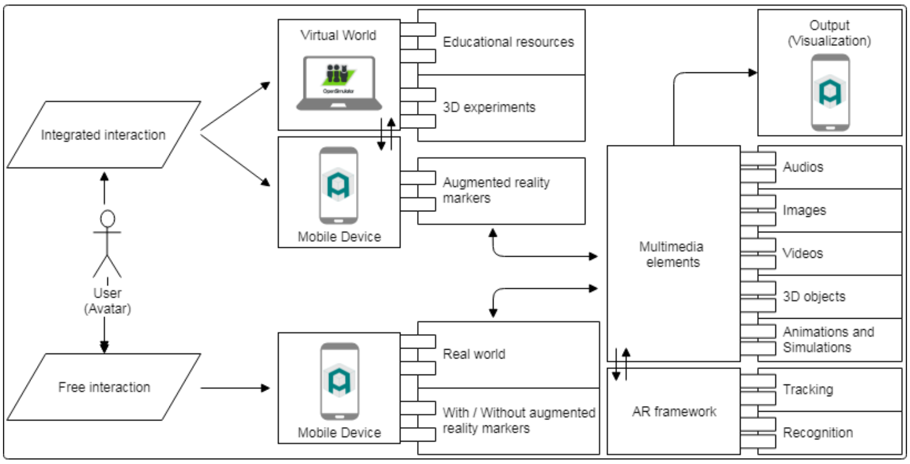

Fig. 1. AR Application Architecture

As to navigate in the AR application, the student has two interactive forms, denominated "Integrated" and "Free" (Figure 1). In the first form, when users access AVATAR's virtual lab, they will find AR markers (simple sprites in the virtual world) associated with the experiments. These markers are there with the intention of combining the virtual elements of AR with the pedagogical resources existent in the virtual lab, by simply pointing their mobile device camera (smartphone or tablet) to the marker and visualizing the educational objects (Figure 2). This process can either be done directly at the computer screen or by a printed version of the markers, which could be handed out by the teacher or found in a textbook. The use of markers is the traditional way of achieving AR, when recognized by a computational vision module, they return the information associated with that marker, which, in this case, corresponds to the physics contents. This way, the user experience is maximized, allowing it to combine the visualization of both simulations, one complementing the other.

The second interactive form amounts to the interaction of the student with the application in an independent manner (Figure 3 and 4). The users can view the educational objects on their mobile devices, anywhere and at any time, without the need to access the virtual lab. This way, the user access, and interaction are eased. This navigation form is built with the markerless AR concept in mind, which consists in the capacity of the application to visualize and perceive the real environment in which the user is in, using the mobile device's camera, gyroscope, accelerometer and other sensors, in order

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to present the virtual elements integrated to this environment, in a seamless manner.

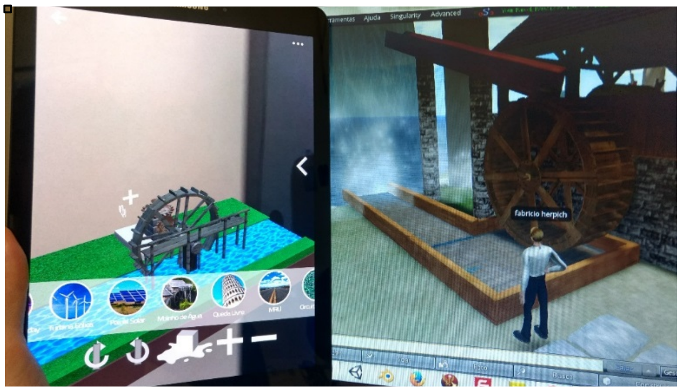

Fig. 2. Integration between the augmented reality app and the virtual laboratory

Relating to the AR application implementation to mobile devices, it was necessary to integrate different frameworks capable of providing tools for this educational solution. Therefore, the 3D Unity tool was used to implement the application and export it for the Android platform, allied with the use of the C# programming language, which allowed the definition of behaviors, via scripts, that the application executes in certain situations. Regarding the aspect that operates the AR functionalities, the framework Vuforia was used, which features a computer vision module that enables the building of interactive experiences and that presents many other resources related to AR [10].

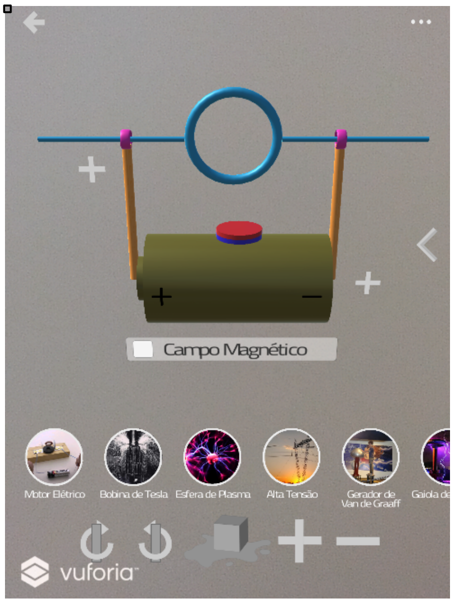

Fig. 3. Animated eletric motor

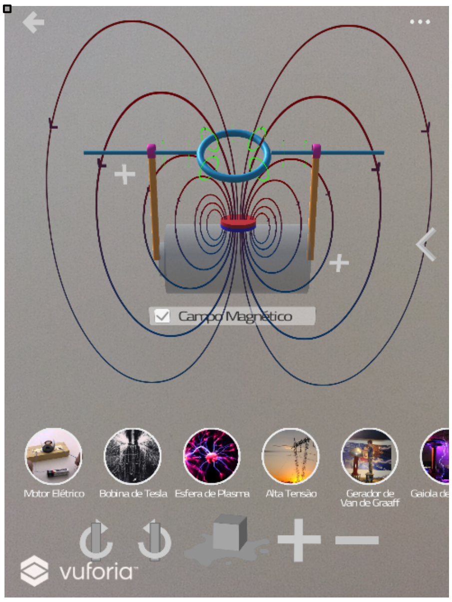

Fig. 4. Magnetic field

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In short, it is possible to list four elementary resources that the application possesses: 1) the chat related option, that the student can eventually use to start a conversation with the chatterbot (conversational agent) ATENA and resolve their questions about the physics experiments; 2) the option in which the student accesses the integrated navigation mode, where the application can be used along with the virtual lab, a textbook or even standalone markers, in order to visualize the educational resources inside a proper context; 3) the free mode, where the student can interact with the experiments without the need for markers or even accessing the virtual lab, visualizing the virtual elements along with the real world around them; and, at last, 4) a user particular inventory, that contains all of the educational resources the student selected as their favorites, with the intention of visualizing them posteriorly, away from the classroom, keeping them in their records.

The application also offers the student a feature to display notes regarding the experiment shown, clarifying the physics principles there present. Another available option consists of the possibility to share on social media screenshots of what the student is currently viewing, to save the object as a favorite, to reposition it to its original location, disposition and size and to watch videos, read and listen to audio clips regarding the experiment at hand. The student can also perform geometric transformations to the pedagogical resources, such as increasing or decreasing its size (scale), moving them around (translation) and spinning them in their axis (rotation), as to perceive them in every possible angle and size. There is, still, the "freezing object" button, which lets the user attach the resource to the device screen, allowing them to reposition it in space and, by "unfreezing" the object again, resetting its position to its new point in space, freeing it from its attachment to the screen. This option gives the user a new form of making spatial transformations, including rotation, scale, and translation.

5 Research results

Along the development of project AVATAR, experiments were done with students of several different ages and educational levels (detailed information can be found in [15], [22], [23], [24] and [25]), aiming to identify if the virtual lab could be perceived as an effective learning resource and contribute to cognitive development. Several verifications could derive from answers received from the participants (with responses between the range of 1 totally disagree and 5 totally agree) of several experiments using the virtual lab built:

An impact in the motivation and in the promotion of change of behavior in obese individuals by combining the use of the virtual world with motion capture devices and interaction with a conversational agent (Santiago, Tarouco and Reategui, [22]).

A positive evaluation of the physics lab and the equivalence of the virtual environment built in a virtual world as an effective learning resource. Through a case study was done with 32 students, the educational resources from the virtual and augmented labs in a general manner were evaluated as useful for learning and capable of expanding its users' knowledge in electricity (both with a median score of 5.0). It was also observed that the experiments contributed to their learning (with a median score of 4.5)

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and that the intelligent agents supplied them with useful information (median score of 3.5) [15].

High quality perceived by the participants in the learning scope with the use of AR. Upon the performance of a case study done with 75 participants of middle school, it was possible to identify that the students understand that the virtual and augmented labs contribute to their learning of the tested subject, that it was efficient in pedagogical terms when compared to other activities done with the same subject and that it also contributes to remind them of the theoretical concepts they previously learned in the classroom (all of these factors scored a median of 4.0) [23].

Educational quality determined by educators. A validation of the AVATAR project by pre-service teachers of Science was performed, where it was observed the benefits involving this approach and its resources, demonstrating the wide acceptance and satisfaction in using the virtual laboratory, showing that the users felt motivated to use it in their pedagogical practice and believe that it can assist students in their learning process. In a more emphatic manner, pre-service teachers agreed that the presented simulations in the virtual and augmented labs were proper learning resources for teaching (average score of 4.82) and that they can contribute in the process of learning for the students (average score of 4.9) [24].

The building of a new comprehension level by integrating theoretical and practical aspects through the extended visualization offered in the virtual laboratory. Based on an evaluation composed of three sixth grade classes with 72 students, it was possible to evince that the participants considered that the simulations presented in the virtual and augmented labs assisted them to visualize the experiment in a more practical and real form (average score of 3.83, with a standard deviation of 1.26). Besides that, the students affirmed that the environment format and the visual interaction motivated their performance of the tasks (average score of 3.84 with a standard deviation of 1,18) [25].

When experiencing the expanded events enabled in a unique form in the virtual and augmented labs, the user feels that the inherent aspects of the context field being studied are relevant to explain and predict the behaviors of that phenomenon when observed in the real world. This new comprehension elicits the reason and utility of the theoretical learning. This is the most important and relevant characteristic of the logical thought in its most advanced stage, as proposed by Piaget [2].

6 Conclusion

This work presented the project AVATAR and its educational modules both for personal computers as well as for mobile devices, demonstrating the usefulness of the AR resources combined with the virtual laboratory. Aiming to provide a better learning experience for students regarding contents related to physics and its natural phenomena, the means of experiments, 3D objects, simulations and other educational resources were used.

The authors of this study have been investigating the hypothesis that, combining both technologies, virtual and augmented reality, it is possible to implement resources

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of great potential for education, where the students will obtain a benefit in their learning, once that they will be able to visualize the physics experiments and materialize the involved physics principles. These many times are not sufficiently clarified in books for the better abstraction of students. The application is also highly available, being accessible on mobile devices anytime and anywhere. This way, it is believed that, through the virtual lab and the AR application, it will be possible to contribute for the development of formal thinking in these students, especially in more practical areas, such as STEM.

In general, some contributions of the AVATAR project are: (1) improving the virtual laboratory design in 3D virtual worlds by promoting the use of intuitive and more pleasant environments; (2) increasing the attention to immersive environments and their potential use to education; (3) providing a tool for science learning and teaching; (4) easing the approach of science lessons to young students by virtual environments; (5) building a conversational agent to support students' actions in the virtual laboratories; and, (6) developing experiments simulating the occurrence of physical phenomena to aid in the development of students' formal thinking.

With the intent of improving the application prototype and making it able to be integrated to the day to day of students, regarding physics concepts, as future stages of the project, the development of new educational resources will be considered. These will aim to be combined with the innovative characteristics of the augmented reality, such as better integrating the virtual resources to the user surroundings without the use of markers and geolocated AR targets. Once finished with the development phase, tests with students using these virtual and augmented reality labs will be performed in order to find new evidence proving their capacity for the development of formal thinking in students.

References

1. Inhelder, B. & Piaget, J. (1961). The growth of logical thinking from childhood to adolescence An essay on the construction of formal operational structures. Basic Books, New York. 356p.
2. Piaget, J. (1950). Play, dreams and imitation in childhood. Routledge, London.
3. Klahr, D., Triona, L. M., & Williams, C. (2007). Hands on What? The Relative Effectiveness of Physical Versus Virtual Materials in an Engineering Design Project by Middle School Children. Journal of Research in Science Teaching, 44 (1), p. 183-203.
4. Scalise, K., Timms, M., Moorjani, A., Clark, L., Holtermann, K., & Irvin, S. (2011). Student Learning in Science Simulations: Design Features That Promote Learning Gains. Journal of Research in Science Teaching, 48 (9), p. 1050-1078.
5. Becker, S. A. Cummins, M., D. A., Freeman, A., & Giesinger, C. H., Ananthanarayanan, V. (2017). NMC Horizon Report: 2017 Higher Education Edition. Austin, Texas.
6. Gruber, V., Schaeffer, L., Silva, J. B., & Restivo, T. (2011). Model for remote data acquisition and monitoring integrating social media, NTIC's and 3G cell phone Networks applied to monitoring small wind turbine. Journal of Telecommunications, 7(1), p. 13–20.
7. Milgram, P. & Kishino, F. (1994). Taxonomy of mixed reality visual displays. IEICE Transactions on Information and Systems, E77–D (12), p. 1321–1329.
8. Chang, K., Chang, C., Hou, H., Sung, Y., Chao, H., & Lee, C. (2014). Development and behavioral pattern analysis of a mobile guide system with augmented reality for painting

DOI: https://doi.org/10.3217/978-3-85125-609-3-08

appreciation instruction in an art museum. Computers and Education, 71, p. 185–197.
9. Furió, D., Juan, M., Seguí, I., & Vivó, R. (2015). Mobile learning vs. traditional classroom lessons: a comparative study. Journal of Computer Assisted Learning, 31(3), p. 189–201.
10. Herpich, F., Guarese, R. L. M., & Tarouco, L. M. R. (2017). A Comparative Analysis of Augmented Reality Frameworks Aimed at the Development of Educational Applications. Creative Education, 8(9), p. 1433–1451.
11. Billinghurst, M. & Dünser, A. (2012). Augmented Reality in the Classroom. IEEE Computer Graphics And Applications, 45(7), p. 56–63.
12. Cai, S., Wang, X., & Chiang, F. K. (2014). A case study of Augmented Reality simulation system application in a chemistry course. Computers in Human Behavior, 37, p. 31–40.
13. Gonzalez-Pardo, A., Rosa, A., & Camacho, D. (2014). Behaviour-based identification of student communities in virtual worlds. Computer Science and Information Systems, 11(1), p. 195–213.
14. Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., & Jovanović, K. (2016). Virtual Laboratories for Education in Science, Technology, and Engineering: A Review. Computers & Education, 95, p. 309–327.
15. Herpich, F., Rossi Filho, T. A., Tibola, L. R., Ferreira, V. A., & Tarouco, L. M. R. (2017). Learning Principles of Electricity through Experiencing in Virtual Worlds. In D. Beck, C. Allison, L. Morgado, J. Pirker, F. Khosmood, J. Richter, & C. Gütl (Eds.), Communications in Computer and Information Science - Immersive Learning Research Network (iLRN) (Vol. 725, pp. 229–242). Cham (ZG) - Switzerland: Springer International Publishing.
16. Yoon, S., Anderson, E., Lin, J., & Elinich, K. (2017). How augmented reality enables conceptual understanding of challenging science content. Educational Technology and Society, 20(1), p. 156–168.
17. Ibáñez, M. B., Di Serio, Á., Villarán, D., & Delgado Kloos, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. Computers and Education, 71, p. 1–13.
18. Mayer, R. E. (2005). Introduction to Multimedia Learning. In R. E. Mayer (Ed.), The Cambridge Handbook of Multimedia Learning. New York: Cambridge University Press, p. 1-18.
19. AVATAR Project. Official web page. Retrieved February, 2018, www.ufrgs.br/avatar.
20. Piaget, J. (1970). The principles of genetic epistemology, Routledge. London. 98 p.
21. Piaget, J. (1951). Psychology of Intelligence. London: Routledge, Kegan Paul.
22. Santiago, F., Tarouco, L., & Reategui, E. (2017). The pedagogical use of the Internet of Things in virtual worlds to encourage a behavior change in obese individuals. IEEE International Conference on Internet of Things (iThings) Exeter, UK, 10, p. 676-682.
23. Herpich, F., Nunes, F. B., Voss, G. B., Sindeaux, P., Tarouco, L. M. R., & Lima, J. V. (2017). Augmented Reality in Geography: an orientation activity in elementary education (Portuguese). Revista Novas Tecnologias na Educação (RENOTE), 15(2), p. 1–10.
24. Nunes, F. B., Zunguze, M., Herpich, F., Antunes, F. F., Nichele, A. G., Tarouco, L. M. R., & De Lima, J. V. (2017). Perceptions of pre-service teachers about a Science Lab developed in OpenSim. International Journal for Innovation Education and Research, 5(5), p. 71–94.
25. Nunes, F. B., Voss, G. B., Herpich, F., Sindeaux, P., Tarouco, L. M. R., & Lima, J. V. De. (2017). Implementation and analysis of a 3D environment for the teaching of Geography (Portuguese). XXVIII Simpósio Brasileiro de Informática Na Educação, p. 766–775.