Contribution of the Computer Technologies in the Teaching of Physics: Critical Review and Conception of an Interactive Simulation Software

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***Abstract*—in the present research, we will synthesize the main research results about the development of interactive computer environments for physics teaching and learning. We will see that few types of software propose environments that take into account the user's erroneous representations in order to make him become aware of his mistakes. The majority of these softwares present modelling activities that are restricted to the automatic collection of experimental data and their analysis under graphical form. As a consequence, we will present the design of computer environments for the learning of the phenomenona of absorption and diffusion of light which will take into account the user's initial representations. The design of these environments is divided in five steps: (1) diagnostic of the user's initial representations; (2) confrontation of the user's initial representations by the simulation; (3) reconstruction by the user of his representations following the completion by the user of the simulation; (4) reconstruction of the user's representations following the presentation by the software of scientific information related to the case studied and (5) assessment of the current state of understanding of the user by the software.**

Keywords—critical review; physical; conception; interactive environments; representations

I. INTRODUCTION

To facilitate the teaching and the learning of the basic physical concepts, the researchers resort more and more to the computer technologies to create interactive environments. To make easier the design of these environments, we carried on a literature review about the use of the computer technology in physics teaching and learning followed by their critical analysis, restraining our study to environments aiming at the modification of initial representations of the users, our main subject of study.

This review allowed us to identify the main difficulties and challenges linked to the building of such interactive environments, and also provided guidelines to conceive them, the main of which consists in using simulation in a step of conceptual change. Using these guidelines, we present the main stages of a step of conceptual change and the different roles the simulation plays in it. We illustrate the sequence of this step by taking into account the initial representations of the science preservice teachers in primary school concerning the properties of light. Finally, we will present he limits of our study and perspectives for future research.

II. OVERVIEW OF THE PROBLEMS WITH RESPECT TO THE TEACHING AND THE LEARNING OF THE PHYSICS

According to the organization of cooperation and economic development (OECD), the problems associated with the teaching and learning of sciences last in spite of multiple reforms of the ministerial programs [1]. The difficulties encountered are multiple: (1) the acquisition of the basics concepts of physics is not easy because the pupil must deconstruct the explanatory model to which he refers to explain a given phenomenon. In this regard, the Canadian Council on Learning [2] note that "the effort necessary to integrate scientific knowledge always more complex and often counter-intuitive can provoke the discouragement of the pupil and even divert him from the study of sciences"; (2) the formation of the teachers in didactics [3] and in sciences ([1], [4], [5]) is not sufficient; (3) the allocated time doesn't allow the teachers to study the construction of the concepts of physics through history, in order to analyze the difficulties met by famous scientists to study different natural and constructed phenomena; (4) the number of pupils in a classroom doesn't permit the teacher to take into account the conceptual difficulties of each pupil and (5) the laboratories as dispensed don't succeed to make the pupils see the interactions that exist between the theory and the practice, and unfortunately these laboratories are often reduced to a simple verification of the theory [6]. To overcome these difficulties, some researchers demonstrate that a teaching with the help of software allows the pupils to achieve meaningful learning: "Successful teaching practices have been implemented internationally in a small number of physics classrooms. These often involve strategically planned tutorials, concept cheks in lecture classes and increased opportunities for student discussion" [7]. Such a teaching requires smaller groups of pupils and a strong formation of the teachers, which is difficult to do in our present systems of education. Thus, according to several researchers, the use of technologies in teaching could offer promising avenues for the formation in sciences. What is the situation in the particular case of physics, central point of the present research?

III. SYNTHESIS OF RESEARCH WORKS ABOUT THE USE OF COMPUTER TECHNOLOGIES IN PHYSICS TEACHING

To facilitate the learning of physics, one resorts more and more to the computer technologies to develop activities of modelling and simulation: mechanical and kinematics ([7],

[8], [9], [10], [11], [12]), electric circuits and electromagnetism [13], [14], [15], [16], [17], [18]), optic ([19], [20], [21]) and acoustic phenomena [22]. Although there are a lot of researches on students' representations concerning mechanical or electrical phenomena, the situation is not the same concerning optics' phenomena where researches on students' representations are rather rare. Moreover, the majority of the activities in these researches are mainly concerned with the automated collection of experimental data and their graphic treatment by the user. In this regard, the automated collection refers to the process of data collection that is assured by a probe plugged to an external port of a computer permitting to take, for example, measures of the temperature or the intensity of the electric current. The data collected by such a process is transmitted thereafter and recorded, permitting their treatment by analysis software such as Regressi [11].

According to our literature review and like other research having achieved a critical review of works that conceives simulation software to support science teaching and learning ([23], [24]), one must note that there are not enough simulation software's that create environments allowing the user to detect his own mistakes explicitly and to favor their evolution toward more scientific representations, as it is the case of the works of Muller, Bewes, Sharma and Reimann [7] and those of Baser and Durmus [14], to mention only them. For example, Baser and Durmus have developed strategies centered on the conceptual conflict among preservice teachers of the primary order in the case of the working of simple electric circuits. In their strategy, the user had to complete at first a questionnaire that served to destabilize him on a conceptual level once he will have verified his answers with the help of the simulation. This stage is indispensable to create the first conditions that will make the user's erroneous conceptions evolve toward more scientific ones.

However, in most cases, the simulation doesn't take into account the user's representations and cannot help him to learn, as the research of Yeo, Loss, Zadnik, Harrison and Treagust [25] have shown. According to these authors, the use of simulated experience on the projectiles motion made the students interact superficially since they kept their intuitive representations on the motion which are erroneous. In the same perspective, Zhou, Brouwer, Nocente and Martin [26] showed that it is possible to create the conceptual change while resorting to experiences that will be followed by a discussion initiated by the teacher where students will argue their ideas following the simulations. But for that to happen, the teacher must have the necessary expertise to manage the erroneous representations of the students. The authors synthesize their results according to what follows: "This study demonstrates that computer-based applets, designed in the light of constructivism, can be helpful in fostering conceptual change/learning, but they should be used in a constructivist teaching environment to be more effective. The effectiveness of computer applets is a function of the applet design, the instructional environment in which they are used, and the teacher's readiness for using new instructional technology. Well-designed new media applications must be used in a constructivist teaching environment by enthusiastic teachers to be effective. University science teachers, normally without a pedagogical background, need to become familiar with the teaching suggestions from cognitive studies and the way that new media works in order to be effective teachers." (p. 47).

Besides, we identified in most analyzed works another problem that is associated to the research methodology used. Indeed, the simulated experimentations have not been achieved with an experimental group and a control group to show the relative merits of the simulation and the traditional laboratory.

With respect to this issue, Smetana and Bell [24] underline what follows: "[…], several studies did not include a comparison group. In these cases, the question remains whether students would have learned as much without the simulation, under the traditional instruction. In those studies that employed a variety of instructional interventions, the contribution of the simulation to student outcomes is uncertain without appropriate controls" (p. 1320).

The present research appears in the lineage of research works led by Baser and Durmus [14] in electricity and propose the conception of computer environments in the case of the optics to the teachers in formation and in service for the primary order.

IV. Conception of Computer Environments

The conception of computer environments for the learning of the phenomenon of the absorption and the diffusion of light will be structured in five stages, as illustrated in figure 1.

What do we mean however by the term "conception of computer environments"? We use it in the sense of Tchounikine [27] according to whom the term CEHL (Computer Environments for Human Learning) refers to the acts of imagining, of thinking, of elaborating, of representing a computer artifact taking into account the educational objectives pursued and the various constraints of the educational situation. The terms of realization or construction refer to making executable on a computer, i.e., to program it.

The first stage serves to evaluate the user's initial representations. In order to do so, the user will have to complete a multiple choices questionnaire already included in the software in which every question is formulated as statement and where the user should indicate, while justifying his choice, if it is true or false. The construction of the questionnaire is described at the end of this section. As an illustration, some questions relative to our theme of study are presented in table I.

In a second stage, the user will confront his anticipated answers with the results of the simulation. To this end, a window in the simulation will be at its disposal to validate himself his answer. It will incite him to throw into question his conceptual structure and he will probably want to change his explanations in the case where some of his anticipated answers revealed to be erroneous. If the user wishes it, the software will invite him to rephrase his explanations again (third stage).

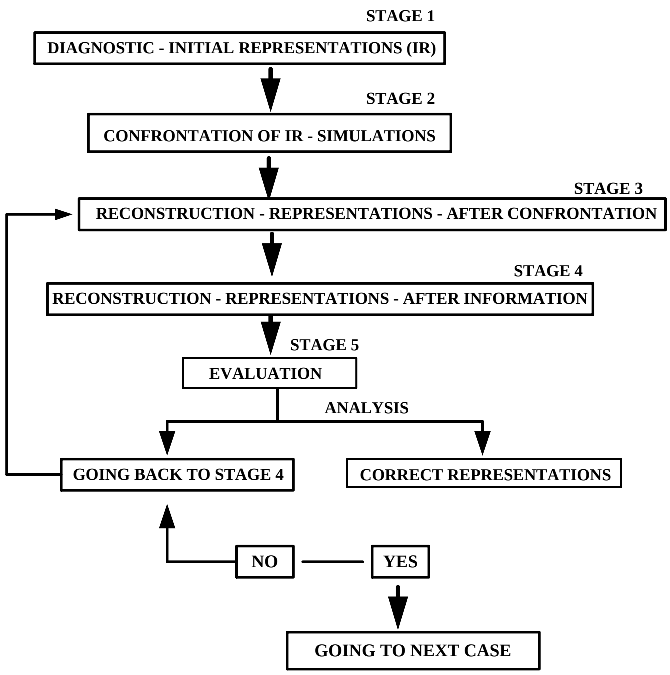

Fig.1. Theoretical schema of Interactive Simulation Software

TABLE I. EXAMPLE OF QUESTIONNAIRE TO MULTIPLE CHOICES - LIGHT PHENOMENA

Question 1: When one illuminates a mirror with a pocket-size lamp, light emitted by the bulb of the pocket-size lamp reaches the mirror and stops there. Justify your choice.	True ☐	False ☐
Question 2: A white sheet of paper is deposited on a table. When one illuminates it with a pocket-size lamp, light emitted by the bulb reaches the paper and stop there. Justify your choice.	True ☐	False ☐
Question 3: One places a yellow tennis ball on a table in a piece illuminated by the light of the day; the bullet will distribute light. Justify your choice.	True ☐	False ☐

According to Zhou [28], this phase of verification with the help of the simulation will facilitate the conceptual change: "The ability for students to visually compare the consequence of their predictions with the realistic process can be helpful in creating cognitive conflict and facilitating conceptual change". (p. 108). In a fourth stage, he will be invited again to rephrase his erroneous answers following the scientific information that will be offered to the user by the software. More precisely, the software will present him a synthesis of the theories, the laws and the scientific models whose acquisition is indispensable to explain the results obtained in the experimentation of the phenomenon and a window of documentation will be dedicated to this end.

The objective is to allow the user to acquire some basic notions with respect to the phenomenon under study, without revealing him however directly the proper scientific explanations.

At this stage, it is likely that he will throw into question his conceptual structure and will rebuild a new structure that, this time, will be correct on a scientific level. In a fifth stage, one will present him again the questionnaire that he has completed at the time of the first stage. For every question, he should evaluate different representations while indicating for each if it is true, partially true, incomplete or false, while justifying his choice (tables II, III and IV).

TABLE II. ASSESSMENT BY THE USER OF DIFFERENT REPRESENTATIONS QUESTION 1

What do you think of the following sentences about lighting a mirror with a pocket-size lamp? Justify your choice.	T¹	PT²	I³	F⁴
Light emitted by the lamp reaches the mirror and stop there because the mirror absorbs light, it doesn't redirect it.	☐	☐	☐	☐
Light propagates itself in a straight way. If a mirror has a plane surface, light reaches it but doesn't reflect upon it. Light can reflect upon the mirror if it makes an angle with it.	☐	☐	☐	☐
The light reaching the mirror reflects upon it when the mirror has a flat surface.	☐	☐	☐	☐
Light will be reflected by the mirror on the wall in front of the source. The mirror doesn't absorb it.	☐	☐	☐	☐

[1]True; [2]Partially true; [3]Incomplete; [4]False

TABLE III. ASSESSMENT BY THE USER OF DIFFERENT REPRESENTATIONS QUESTION 2

What do you think of the following sentences about the lighting of a white sheet of paper deposited on a table? Justify your choice.	T¹	PT²	I³	F⁴
Light emitted by the lamp reaches the paper and stops there because light stops where one illuminates.	☐	☐	☐	☐
Light emitted by the lamp reaches the paper and stops there. The white sheet of paper doesn't reflect light because it is an opaque body.	☐	☐	☐	☐
The two bodies are different: light is transparent, whereas the sheet of paper is opaque. It is for that reason that light reaches the paper and stops there.	☐	☐	☐	☐
Light doesn't reflect upon the paper since it is an opaque body.	☐	☐	☐	☐

[1]True; [2]Partially true; [3]Incomplete; [4]False

TABLE IV. ASSESSMENT BY THE USER OF DIFFERENT REPRESENTATIONS QUESTION 3

What do you think of the following sentences about a yellow tennis ball placed on a table in a piece illuminated by the light of the day? Justify your choice.				
	T[1]	PT[2]	I[3]	F[4]
The ball distributes a part of light; the light we see is the light that is reflected by the object (yellow). The object reflects a part of the light of the sun and it absorbs a part of it.	□	□	□	□
The ball doesn't distribute light because it is an opaque body.	□	□	□	□
The ball doesn't distribute light because the ball is not a source of light.	□	□	□	□
The ball doesn't distribute light because the color is not a source of light, it is rather what our eye discerns.	□	□	□	□

[1]True; [2]Partially true; [3]Incomplete; [4]False

In this stage, the user should not resort to the simulation, but rather to refer to his new knowledge and to write down in a window his assessment, as asked. In the case where the user didn't really understand the phenomenon, his answers risk to destabilize it, or even to sow a doubt.

The conception of such an interactive environment must be based upon the identification at first of the representations of the user with respect to the scientific phenomena being studied, here the properties of light. To this end, we analyzed the answers to a paper-pencil questionnaire distributed to a hundred-twenty (120) preservice teachers in a course on the didactics of the sciences. We also took into account the few research works on the representations of the teachers and pupils with respect to the properties of light ([29], [30], [31]). If the analyses done by the user are appropriated, our interactive software will invite him to complete a questionnaire of reinforcement that will ask new questions.

V. CONCLUSION AND LIMIT OF OUR SURVEY

Following our analysis of research works on the development of computer environments, very few pursue the goal of understanding what they really bring to correct the erroneous representations of the pupils, as reported in the international literature, and that the traditional teaching doesn't succeed in correcting, as several organisms, like the OECD [1], confirmed it.

Also, very few research works have tried to see how the multimedia resources could be used to take into account the mistakes of the learners in order to generate the conceptual conflict and to propose environments with which the user must interact in order to re-establish his conceptual balance and that, in the perspective of conceptual change advocated by Posner, Strike, Hewson and Gertzog [32]. Also, few researches worried about the users' requirements in order to use the computer tools adequately, like the graphic representation as a tool of acquisition of knowledge. Several researches showed that the pupils have serious difficulties to use such a graphic representation correctly [32]. The following passage, borrowed from Muller, Bewes, Sharma and Reimann [7] supports our conclusion: « […] limited research has been conducted on how resources like linear multimedia can be altered promote conceptual change. Multimedia research has investigated student learning of scientific topics […], but the issue of misconceptions has rarely been addressed. Studies have also typically been conducted in controlled laboratory environments, with learners who have little or no prior knowledge neither about the subject matter nor experience in the ways of knowing, learning and thinking in the domain. »

Finally, with regard to the second aspect of our research, we intend to pursue our work of conception, notably in the scientific notions that the interactive environment will present to the user (stage 4). For it, we are achieving a conceptual analysis in order to identify the most important scientific notions than the user should acquire. This analysis will give account of the erroneous theories constructed by the scientists during history and will serve to valorize the user's erroneous representations among others. As for the part of realization (according to Tchounikine) of the proposed environments, it will be developed once our work of conception will be advanced. To this topic, we are conscious that the realization of the computer part could bring us to review some elements of our conception for reasons bound to their programming. Thus, we think of resorting to other supports as the video [11] in the case of the experimentations that would be difficult to achieve on the screen of a computer.

REFERENCES

[1] Organization of cooperation and economic development (OCDE). Declining enrolment in science & technology Studies. Is it real? What are the causes? What can be done?, 2005.

[2] Conseil canadien sur l'apprentissage. Apprentissage informel de la science au Canada. Carnet du savoir, 2007.

[3] N. Coppens, G. Rebmann, and V. Munier. "Suivre l'évolution des conceptions des élèves en mécanique : développement et évaluation d'exercices informatisés," Didaskalia, vol. 35, 2009, pp. 37-58.

[4] A. Métioui and L. Trudel. "Quebec secondary physics teachers and modern science: The case of the concept of matter," The International Journal of Science in Society, vol. 3, no 1, 2012a, pp. 177-190.

[5] M. Walport. Science and mathematics secondary education for the 21st century. Report of the Science and Learning Expert Group, 2010. Innovation and Skills (England):

[6] http://interactive.bis.gov.uk/scienceandsociety/site/learning/files/2010/02/Science-and-Learning-Expert-Group-Report-Annexes-31.pdf

[7] N. Nonnon, and A. Métioui. "L'appropriation du processus de vérification expérimentale par des étudiants en formation des maîtres au secondaire : exemple de la diffusion de la chaleur dans un liquide," Res Academica, vol. 21, no 1, 2003, pp. 39-61.

[8] D. A. Muller, J. Bewes, M. D. Sharma and P. Reimann. "Saying the wrong thing: Improving learning with multimedia by including misconceptions," Journal of Computer Assisted Learning, vol. 24, no 2, 2008, pp. 144–155.

[9] M. Couture. "Realism in the design process and credibility of a simulation-based virtual laboratory," Journal of Computer Assisted Learning, vol. 20, no 1, 2004, pp. 40-49.

[10] Z. Smyrnaiou, and A. Weil-Barais. "Évaluation cognitive d'un logiciel de modélisation auprès d'élèves de collège," Didaskalia, vol. 27, 2005, pp. 133-149.

[11] P.-K. Tao and R.-F. Gunstone. "The process of conceptual change in force and motion during computer-supported physics instruction," Journal of research in science teaching, vol. 36,l no 7, 1999, pp. 858-882.

[12] L. Trudel and A. Métioui. "Effect of a video-based laboratory on the high school pupils' understanding of constant speed motion," International Journal of Advanced Computer Science and Applications, vol. 3, no 5, 2012, pp. 71-76.

[13] G.-G. Zhou, W. Brouwer, N. Nocente, and B. Martin. "Enhancing conceptual learning through computer-based applets: The effectiveness and implications," Journal of Interactive Learning Research, vol. 16, no 1, 2005, pp. 31-49.

[14] M. Baser. "Effects of conceptual change and traditional confirmatory simulations on preservice teachers' understanding of direct current circuits," Journal of Science Education and Technology, vol. 15, no 5, 2006, pp. 367-381.

[15] M. Baser and S. Durmus. "The effectiveness of computer supported versus real laboratory inquiry learning environments on the understanding of direct current electricity among pre-service elementary school teachers," Eurasia Journal of Mathematics, Science & Technology Education, vol. 6, no 1, 2010, pp. 47-61.

[16] R. H. Berube. Computer simulated experiments for electric circuits using electronics workbench Multisim, New Jersey: Prentice Hall, 2004.

[17] S. Labrique, D. Grenier, and F. "Labrique. Entre savoir et savoir-être, du rôle des TIC dans le processus d'apprentissage du génie électrique : compte rendu d'innovation," Didaskalia, vol. 24, 2004, pp. 104-131.

[18] M. Ronen, and M. Eliahu. "Simulation - a bridge between theory and reality: The case of electric circuits," Journal of Computer Assisted Learning, vol. 16, 2000, pp. 14-26.

[19] C. Vreman-de Olde, and T. de Jong. "Student-generated assignments about electrical circuits in a computer simulation," International Journal of Science Education, vol. 26, no 7, 2004, pp. 859-873.

[20] C. Buty. "Richesses et limites d'un « modèle matérialisé » informatisé en optique géométrique," Didaskalia, vol. 23, 2003, pp. 39-63.

[21] B. Eylon, M. Ronen, and U. Ganiel. "Computer simulations as tools for teaching and learning: Using a simulation environment in optics," Journal of Science Education and Technology, vol. 5, no 2, 1996, pp. 93-10.

[22] C. Viudez. "Expérimentation d'un environnement informatique dans le cadre de travaux pratiques sur l'interféromètre de Michelson en licence: compte rendu d'innovation," Didaskalia, vol. 23, 2003, pp. 147-161.

[23] A. Séjourné. "Éléments théoriques pour la conception d'un hypermédia en sciences physiques et pour l'analyse de l'activité des élèves : le cas des phénomènes sonores," Didaskalia, vol. 23, 2003, pp. 65-99.

[24] S.-W.-L. Lee, C.-C. Tsai, Y.T. Wu, M.J. Tsai, T.-C. Liu, F.K. Hwang, and C.Y. Chang. "Internet-based science learning: A review of journal publications," International Journal of Science Education, vol. 33, no 14, 2011, pp. 1893-1925.

[25] L.K. Smetana and R.L. Bell. "Computer simulations to support science instruction and learning: A critical review of the literature," International Journal of Science Education, vol. 34, no 9, 2012, pp. 1337-1370.

[26] S. Yeo, R. Loss, M. Zadnik, A. Harrison, and D.F. Treagust. "What do students really learn from interactive multimedia? A physics case study," American Journal of Physics, vol. 72, no 10, 2004, pp. 1351-1358.

[27] G.G. Zhou, W. Brouwer, N. Nocente, and B. Martin. "Enhancing conceptual learning through computer-based applets: The effectiveness and implications," Journal of Interactive learning Research, vol. 16, no 1, 2005, pp. 31-49.

[28] P. Tchounikine. Précis de recherche en ingénierie des EIAH, 2009. Récupéré le 18 août 2012 du site de l'auteur :

[29] http://membres-liglab.imag.fr/tchounikine/Precis.html

[30] G.G. Zhou. "Conceptual change in science: A process of argumentation," Eurasia Journal of Mathematics, Science & Technology Education, 6(2), 2010, pp. 101-110.

[31] A. Métioui and L. Trudel. "The model of the rectilinear propagation of light and the study of the variation of the size of a shadow," US-China Education Review, vol. 2, no 9, 2012b, pp. 173-186.

[32] [30] K. Ravanis, K. Zacharos, and A. Vellopoulou. "The formation of shadows: The case of the position of a light source in relevance to the shadow," Acta Didactica Napocensia, vol. 3, no 3, 2010, pp. 1-6.

[33] N.J. Selley. "Children's ideas on light and vision," International Journal of Science Education, vol. 18, no 6, 1996, pp. 713-723.

[34] G. Posner, K. Strike, P. Hewson, and W. Gertzog. "Accomodation of a scientific conception: Toward a theory of conceptual change," Science Education, vol. 66, no 2, 1982, pp. 211-228.

[35] W.M. Roth, and M.K. McGinn. "Graphing: a cognitive ability or a cultural practice?," Science Education, vol. 81, 1997, pp. 91-106.

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