The Impact of Integrating Computer Simulations and Videos on Senior Secondary School Learners' Performance Achievement on Atomic Physics and Radioactivity Concepts

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Abstract This study explored the impact of integrating computer simulations and videos in addition to lecture discussions on learner's understanding of concepts on atomic physics and radioactivity. The study was a randomly assigned pre-test post-test counter balanced quasi-experimental design involving two grade 11 classes at a secondary school located in Kitwe on the Copperbelt Province of Zambia. One class was assigned to be the experimental group while the other was made the comparison group for six lessons. Post-test results were analysed following teaching using computer simulations, video and lecture method (experimental group) and using videos only and lecture method (comparison group). In the second half the groups were swapped for purposes of counterbalancing. Post-tests on achievement were analysed yielding a comparison of the groups under the different treatments. Results indicated that the mean of the experimental group ($E_{post-test}$ = 66.60%) was significantly higher than the mean of the comparison group ($C_{post-test}$ = 45.68%) (t = 4.179; df, 37; p = .000; α = .05). The results indicated a substantial effect size by Cohen's *d* of 1.34. Overall, the results suggest that integrating computer simulations and videos into teaching atomic physics and radioactivity significantly enhances learners' performance.

Keywords: achievement, atomic physics, PhET, radioactivity, simulation, video

1. Introduction

In many parts of the developing world, science educators often meet the challenge of captivating their students to learn science joyously and to an effect. The reasons are many, including the lack of standard equipped laboratories and classrooms. On the other hand, teachers may lack the creativity and reflection to use resources that are accessible to them in their locality and online. Some topics like atomicity and radioactivity are themselves noteworthy challenging topics to teach and to comprehend, especially in the absence of resources for experimentation, observation, and analysis. Further, some subjects among them physics are considered difficult by learners and teachers [1,2]. For Zambia, atomic physics and radioactivity are important topics in the senior secondary school syllabus but prove difficult for learners [3]. It now takes even more importance given the country's strategic thrust to develop the nuclear industry and technologies for their potential to contribute to development to power generation and to applications in agriculture, medicine and telecommunications. It is important to explore methods of teaching and learning that are likely to enable to the appreciation of atomicity and radioactivity even when the laboratories lack sophistication in terms of equipment. The world wide web provides a rich resource that may be explored for case studies and resources that may be used for good teaching and learning in physics and other natural sciences.

The use of computer simulations and videos opens up a new world for science educators permitting learners to situate learning using technological tools that have become a part of their lives. Windschitl [4] pointed out that with simulations, learners can predict how a process unfolds, be in a position to test these predictions, as a result, an 'internal discourse' can be encouraged to occur within the learner's minds. In short, they become learning activated. Computer simulations enable learners to view phenomena, events, processes and activities that otherwise may not have been available or that may be too fast, too slow, too small, too large or too dangerous to be done or studied in classrooms [5]. The efficacy of computer simulations in learning achievement has been demonstrated in many studies. However, many studies are often

designed to demonstrate the efficacy of instruction with technologies over traditional approaches that do not employ them [6].

2. Purpose of Study

Given the above background, this study was an action research exploring the efficacy of computer simulations used in combination with videos in the learning of atomic physics and radioactivity concepts at the seniour secondary school level. It explores the use of a counterbalanced quasi-experiment design to cross-validate the impacts and to overcome the criticism of studies that pit innovative teaching approaches against ineffectual 'traditional' methods. This paper is concerned with reporting the results of analysing the data for achievement performance following a 12-lesson series. The objectives of the study were as follows:

i. To design and implement an intervention integrating computer simulations and videos for teaching and learning of atomic physics and radioactivity concepts at grade 11 level.

ii. To assess the impact of computer simulations and videos on achievement performance among grade 11 learners studying atomic physics and radioactivity.

We hypothesise a positive impact on the basis of the results from previous studies in other contexts [7] and different subjects, e.g., chemistry 'kinetic molecular theory' [8] and biology 'genetics' [9] and cell theory [10]. Effect sizes as much as Cohen's d of 0.81 [8], 0.87 [9], and 1.54 [10] were reported. In some studies, these effects are possibly due to the arousal of interest generated by computer simulations [11] which we test in this case study by counter balancing and observing the results when further instruction is provided with video only.

3. Research Methodology and Design

This action research provides a case study of the use of a pre-test post-test counter balanced quasi-experimental research design to explore impact of use of online resources for teaching and learning a unit in physics.

3.1. Research Site and Participants

The action research was conducted at St Francis Secondary School, a co-educational school located in Bornite road, Garneton in the outskirts of Kitwe. The target participants were grad 11 learners. The school has four grade 11 classes with an enrolment of 150 learners. The two classes (grade 11B and grade 11C) that studied the Physics (5124) syllabus were selected for the study. There were 77 learners in these classes. By toss of a coin, one of the classes was chosen to be in the experimental group (11C) in Phase 2 while 11B became the comparison group (11B). The research was structured into three phases as shown in Table 1.

3.1.1. Phase 1: Pre-intervention

The two classes were pretested in Phase 1 (Table 1) using a teacher developed achievement test. The test covered content drawn from Unit 12 'Atomic Physics' from the physics syllabus (5124). Some of the question items were selected from past final national examinations of the Examination Council of Zambia between 2009-2016. The test comprised of knowledge and application type questions. Some questions required calculations and plotting of graphs. An example question is in Table 2.

Table 1. Structure of the action research

	Phase 1: Pre-intervention (**P1**)- *Planning & Pre-testing*	Phase 2: Intervention (**P2**)- *Implementing 6 lessons & Post-testing*		Phase 3: Counter balanced (**P3**)- *Implementing 6 lessons & Post-testing*	
1. Experimental Class	$O_{1(11C)}$ (achievement test)	X_1 (simulation, video, lecture)	$O_{2(11C)}$ (achievement test)	X_2 (video, lecture)	$O_{3(11C)}$ (achievement test)
2. Comparison Class	$O_{1(11B)}$ (achievement test)	X_2 (video, lecture)	$O_{2(11B)}$ (achievement test)	X_1 (simulation, video, lecture)	$O_{3(11B)}$ (achievement test)
3. Major content		atomic structure, nuclear radiations, emission detection		Radioactive decay and half life, fission and fusion, applications	

Table 2. Sample item in pre-and post achievement test

a. What are some two uses of radioactive substances?
…… [2 marks]
b. The diagram below shows a radioactive source emitting alpha, beta and gamma radiation which are allowed to pass through an electric field.
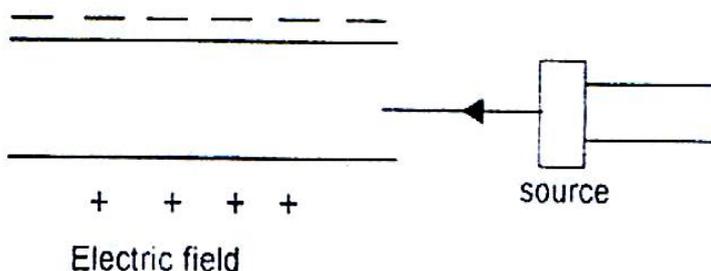
On the diagram above, draw the possible paths taken by each of the three radiations emitted as they pass through the electric field.

[3 marks]

3.1.2. Phase 2 Intervention: Six Lessons

The interventions consisted of a series of lessons implemented in two phases P2 and P3 in Table 1. The experimental group was taught with the integration of 4 computer simulations and 5 videos in 6 consecutive lessons in Phase 2 and with videos only in Phase 3 for another 6 lessons. The comparison group started with videos in Phase 2 and switched to simulations and videos in Phase 3. The videos and the content being presented were common to both groups of learners.

Table 3 summarises the content and gives example of the videos and computer simulations. The videos were sourced from YouTube while the computer simulations were freeware PhET Interactive Simulations developed at the University of Colorado Boulder.

For example, in Phase 2 a short video basic atomic structure https://www.youtube.com/watch?v=lP57gEWcisY was watched followed by discussion. A subsequent lesson introduced a computer simulation on atomic structure: https://phet.colorado.edu/en/simulation/build-an-atom that combined the simulation with gaming. The learners could learn electronic configuration, location in the periodic table, and atomic and mass numbers through the simulation.

The learners also worked with their video or simulation to complete tasks in the lessons which they worked as groups. For example, after watching video and simulations on radiations and their detection, e.g., https://www.youtube.com/watch?v=VTHQYjkCqV0 and https://www.youtube.com/watch?v=wsspFQn0mWM they had to complete a task such as that in Table 3.

3.1.3. Phase 3 Intervention: Six Lessons

In the counterbalanced Phase 3, the two groups continued to explore content on nuclear fusion and fission, and radioactive applications, e.g., carbon dating through video only for the experimental group from Phase 2 and through combination of simulation and video for the comparison group from Phase 2. Examples included simulated fission (Figure 2), https://phet.colorado.edu/en/simulation/nuclear-fission, nuclear fusion video, https://www.youtube.com/watch?v=Cb8NX3HiS4U, and radio-dating simulation (Figure 3), https://phet.colorado.edu/en/simulation/radioactive-dating-game.
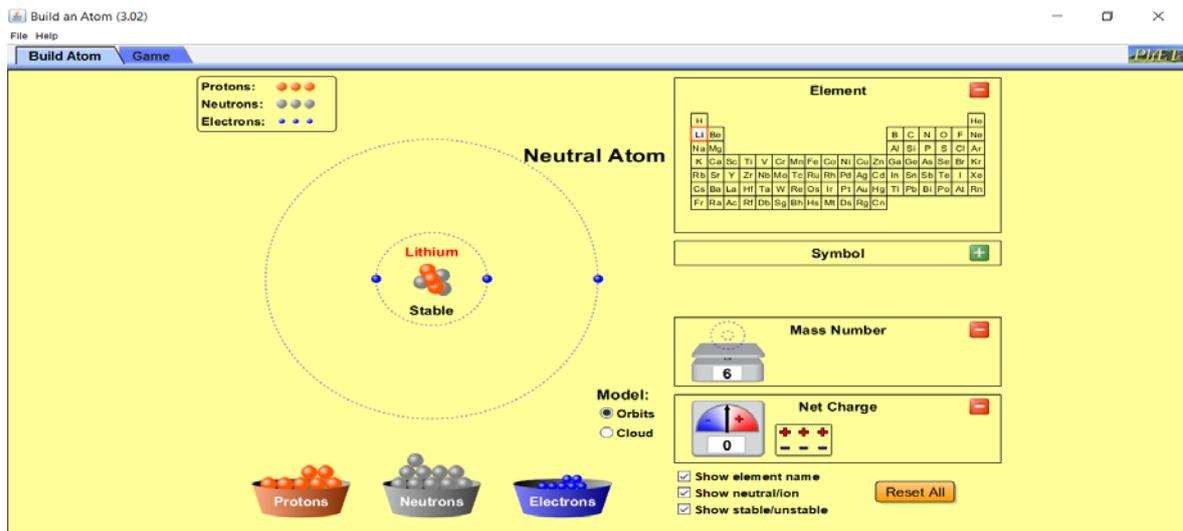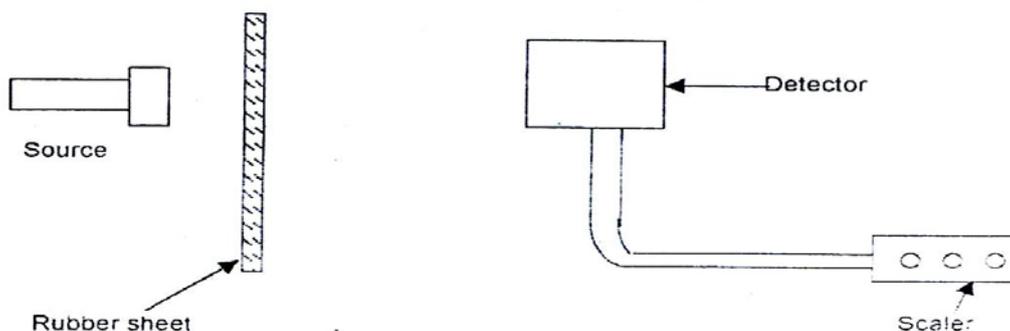

Figure 1. Screen shot of computer simulation on atomic structure (Source: PhET)

Table 3. Sample question for class activity

Question 1

The figure below shows the same source being used with a detector and scalar to monitor the thickness of rubber in a rubber industry.

(a) With ideas coming from the videos, state the suitable kind of radiation from this source that is used for monitoring the rubber thickness. Give a reason for your answer.
(b) From the video of uses of isotopes and radiations, explain how the thickness of rubber is monitored.
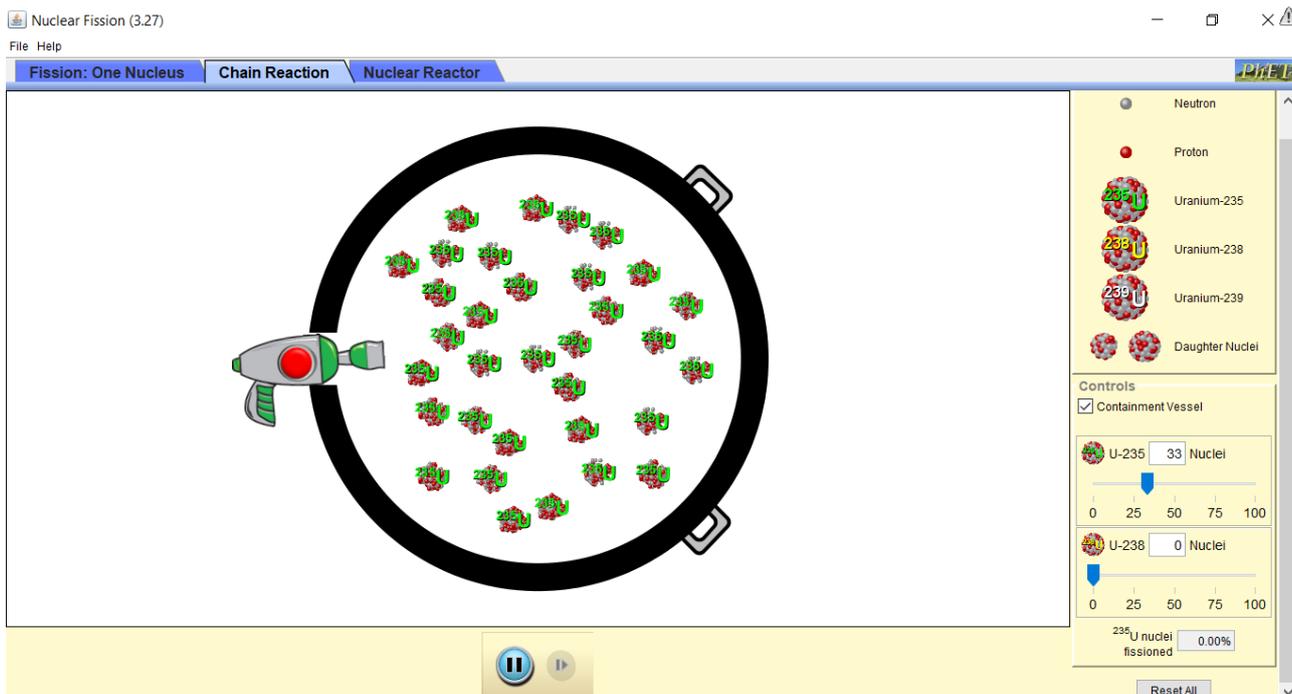
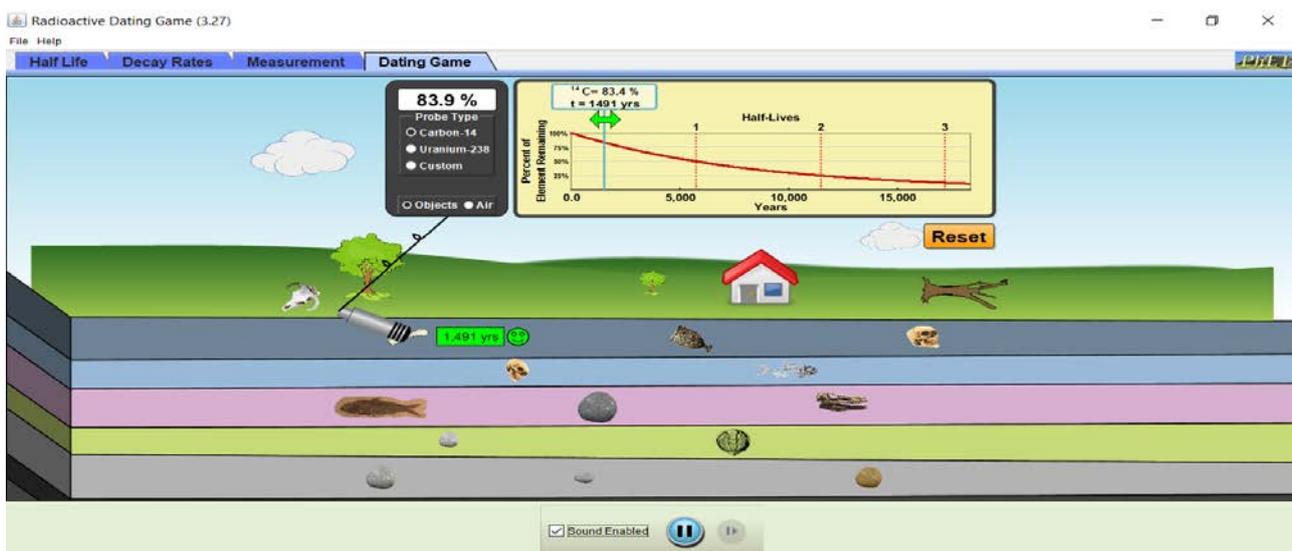**Figure 2.** Screenshot from PhET fission simulation

Figure 3. Screenshot from PhET fission simulation.

As in Phase 2, learners had to complete activities to discuss, answer questions, write something or to construct graphs as they worked with or after working with simulations or videos. These were carried out in the course of six lessons in each phase.

3.2. Data Analysis

Descriptive and inferential data analysis was achieved via the use of the Statistical Package for Social Scientists (version 20.0). A predetermined alpha level of .05 was used for testing the hypotheses.

4. Results and Findings

The study was a randomly assigned pre-test post-test counter balanced quasi-experiment design. Pre- and post-measures were given in the form of achievement tests and the results are summarised in Table 4. It shows the results in the achievement tests from the pre-testing Phase 1 and through the two phases of the intervention P2 and P3 that involved 12 lessons. The two groups of learners were not significantly different in their pre-test scores as assessed via a Mann-Whitney test ($E_{mean\ rank} = 27.52$; $C_{mean\ rank} = 27.48$). The Mann-Whitney test showed the rank differences not to be statistically different ($U = 364.00$; $p = 0.993 < \alpha = 0.05$). This test was undertaken after the Shapiro-Wilk test showed that the distribution of the pre-test scores was not normal ($W_{df = 54;\ p = 0.002} = 0.925$). Overall, the classes were at comparable levels of understanding. Generally they lacked knowledge on the concepts of radioactivity, half-life, background radiation, alpha and beta particles, nuclear fission, nuclear fusion, and applications of radioactive substances.

Table 4. Learner achievement scores on atomicity and radioactivity after video and simulation lessons.

Group	n	Phase 1: Pre-intervention (**P1**) Score (%) (sd)	n	Phase 2: Intervention (**P2**) (6 lessons) Score (%) (sd)	P1-P2 gain (%)	Effect Size Cohen's *d*	n	Phase 3: Counter balanced (**P3**) (6 lessons) Score (%) (sd)	P1-P2 gains (%)	
1. Experimental (video & simulation) (**E**)	27	23.85 (12.69)	20	66.60 (15.21)	+42.75[*]		19	83.22 (10.89)	+16.72	Video only
				Effect Size (Cohen's d)		1.34[1]			0.387[1]	
2. Comparison (**C**) (video only)	27	22.11 (12.89)	19	45.68 (16.06)	+23.57[*]		23	77.65 (17.74)	+31.97	Video + Simulation
3. Differences (**E-C**)		+1.74		+20.92[*]	+19.18[*]			+5.57	+ 15.25	

[*]Significant p < .05, two tailed t-test.
[1]Cohen's *d* calculator used can be found at (http://www.socscistatistics.com/effectsize/Default3.aspx).

Table 4 shows significant gains for both groups in their achievement scores from pre-test to post-teat after the intervention phase (P2). The mean of the experimental group ($E_{post-test}$ = 66.60%) showed superior gains of some 42.75 percentage points from pre- to post-test; this compares to 23.57 percentage points gain for the comparison group ($C_{post-test}$ = 45.68%). The experimental group scored significantly better than the comparison group after six lessons (t = 4.179; df, 37; p = .000; α = .05). The effect size (Cohen's *d* = 1.34) calculated via an online effective size calculator suggested that the score of the average learner in the experimental group scored 1.34 standard deviations above the average learner in the control group.

Further to the above, Table 4 shows also the results after counterbalancing interventions (P3) for the last 6 lessons. In this phase, the original experimental group now used video only and the former comparison group used both video and computer simulation. In both groups, the students continued to learn and show gains in achievement. In the video only class, they gained 14.62 percentage points ($M_{video\ only}$ = 83.22; s = 10.89) and in the comparison group they gained 31.97 percentage points ($M_{video\ +\ simulation}$ = 77.65; s = 17.74). Inclusion of simulation software appeared to impact on the achievement. However, the difference in the two groups remained non-significant at the .05 alpha level ($E_{video\ only}$ - $C_{video\ +\ simulation}$ = 5.77; t = 1.269; p = 0.212). This provides evidence that introducing the computer simulations had significant value addition to learning radioactivity and atomicity. The counterbalancing appears to have effectively compensated the group that previously had used video only.

5. Discussion and Implications

Overall, the above results point to a successful intervention in which video and computer simulation technologies were used to support the learning of atomicity and radioactivity. What has been demonstrated is the efficacy of these technologies when used to support learning some otherwise abstruse concepts associated with atomicity and radioactivity. Computer simulations enhanced this efficacy perhaps because in the simulations learners were able to take control and input data values and observe the simulation and the results. This adds a hands and minds-on dimension and a tinge of reality when using the technology besides the noteworthy enhancement of learning environments and learning motivation [12]. Results elsewhere in the world point in the same direction [13] and Cohen's *d* effect sizes in the magnitude of 0.81 have been reported [8]. In other contexts, computer simulations are thought to provide feedback that minimises abstractness of concepts [14]. For Zambia, computer simulations may alleviate the poor levels of performance in physics and other natural science subjects that continue to feature in examination reports [3].

What this would also suggest is the need for effective pedagogical use and knowledge of ICTs when teaching topics such as those in this study the part of physics teachers. Mishra and Kohler [15] that this type of knowledge as technology pedagogical content knowledge and that relates to how a teacher uses technologies in making teaching and learning more effective. It would seem that physics teachers need to become innovative and at the same time to appreciate, what Kalogiannakis [16] found to be the "more active and more dynamic" roles they ought to adopt when using ICT to teach physics.

The design and results of this study also point to the importance of a counter balanced quasi-experiment in classroom action research. Counterbalancing allows both the experimental and control group to experience both conditions being tested. In this case, the researchers did not want to deny the comparison group the privilege to experience computer simulations. These provided positive experience for the group and even compensated it in terms of gains in achievement. Studies that compare innovative teaching including the integration of technologies are common, but the ethical question remains that of placement of students in 'traditional' conditions known for their weaker impacts or less desirability. This study also contributes a case for the creative and reflective use of resources and freeware that come online. A lot of classrooms in the developing world lack standard equipped laboratories and the use of videos and computer simulations provides a rich experience that approximates reality for the learner in a superior way than classroom chalk and talk. We conjecture that introducing learners to appropriate software's and their use can end up activating them to explore, on their own and in their own time, scientific activities and reports that flood the World Wide Web.

References

[1] Jenkins, E. W. & Nelson, N. W. (2005). Important but not for me: Students attitudes towards secondary school science in England. *Research in Science and Technological Education, 23*(1), 41-57.

[2] Aykutlu, I., Benen, S. & Bayrak, C. (2014). Teacher opinions about the conceptual challenges experienced in teaching physics curriculum topics. Procedia - Social and Behavioural Sciences, 174 (2015), 390-405.

[3] Examination Council of Zambia (2015). *2014 Examination Performance Report: Natural Sciences*. Examinations Council of Zambia, Lusaka.

[4] Windschitl, M. (1998). The WWW and classroom research: What path should we take? *Educational Researcher, 27*(1), 28-33.

[5] Bilan, B. J. (1992). Computer simulations: An integrated tool. Paper presented at the SAGE 6th Canadian Symposium, The University of Calgary, at https://files.eric.ed.gov/fulltext/ED371538.pdf.

[6] Eckhardt, M., Urhahne, D., Conrad, O., & Harms, U. (2013). How effective is instructional support for learning with computer simulations? Instructional Science, 41, pp. 105-124.

[7] Jimoyiannis, A. & Komis, V. (2001*).* Computer simulations in physics teaching and learning: A case study on students' understanding of trajectory motion. *Computers and Education, 36*(2), 183-204.

[8] Stern, L., Barnea, N. & Shauli, S. (2008). The effect of a computerized simulation on middle school students' understanding of the kinetic molecular theory. *Journal of Science Education and Technology, 17*(4), 305-315.

[9] Gelbart, H., Brill, G. & Yarden, A. (2009). The impact of a web-based research simulation in bioinformatics on students' understanding of genetics. Research in Science Education, 39(5), pp. 725-751,

[10] Kiboss, J. K., Ndirangu, M., & Wekesa, E. W. (2004). Effectiveness of a computer-mediated simulations program in school biology on pupils' learning outcomes in cell theory. *Journal of Science Education and Technology, 13*(2), 207-213.

[11] Consortini, A. (2013). Advantages and disadvantages of using computer in education and research. At https://www.osapublishing.org/DirectPDFAccess/D49C3FB7-C5F2-BB49-3F7C4647C2CF2CDA_269194/ETOP-2013-EThB1.pdf?da=1&id=269194&uri=ETOP-2013-EThB1&seq=0&mobile=no.

[12] Basri, W., Alandejani, J.A., & Almadani, F.M. (2018). ICT Adoption Impact on Students' Academic Performance: Evidence from Saudi Universities. *Education Research International, 2018*.

[13] Bozkurt, E. & Ilik, A. (2010). The effect of computer simulations over student's belief and physics success. *Procedia Social and Behavioural Sciences, 2*(2010), 4587-4591.

[14] Sentongo J., Kyakulaga, R. & Kibirge, I. (2013). The effect of using computer simulations in teaching chemical bonding: experiences with Ugandan learners. *International Journal of Educational Sciences, 5*(4), pp. 433-441.

[15] Mishra, P. & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teacher College Record, 108*(6), 1017-1054.

[16] Kalogiannakis, M. (2004). A virtual learning environment for the French physics teachers. *Education and Information Technologies, 9*(4), 345-353.