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SIMULATION AND INQUIRY-BASED LEARNING IN PHYSICS TEACHING

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A R T I C L E I N F O

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A B S T R A C T

In this paper, we attempt to explore the effect of an inquiry-based learning scenario via a computer simulation on students' performance in physics and on the conceptual understanding of heat and temperature. Two hundred and thirty-four Moroccan middle school students participated in this study. We used the Thermal Concept Evaluation (TCE) test to measure student performance and to assess their conceptual understanding of heat and temperature. The TCE test is a conceptual test consisting of 26 multiple choice items. Each wrong choice for each item corresponds to a specific naive conception of the concepts of heat and temperature. We adopted a quasi-experimental design with pretest and posttest. Participants were divided into three groups for the three different learning scenarios: inquiry-based learning (GAI), learning via computer simulation (GSV), and inquiry-based learning via computer simulation (GAISV). The pre-test and post-test scores of the three groups were analyzed using comparative analysis and F-test to determine whether there is a significant difference in students' performance in learning the concepts in physics. The results show us that the students in the group of the inquiry-based learning scenario via a simulation (GAISV) performed better than those in the group of the inquiry based learning scenario (GAI) and better than those in the group of the learning scenario via simulation (GAI). The difference between the Normalized learning gains of the three groups is statistically very significant. The results of the present research report positive effects of inquiry-based learning via computer simulations on students' performance in physics and on the conceptual understanding of the concepts of temperature and heat.

INTRODUCTION

In physics didactics, research has often reported that the traditional approach to teaching physics fails to help students develop a conceptual understanding of the most fundamental concepts (Pundak & Rozner, 2008; Mazur, E ;1997; Redish et al, 1998.). Inquiry-based learning (IBL) presents itself to physics teachers as an innovative alternative to address this situation. Indeed, numerous studies have shown the positive effects of implementing this approach, particularly in medicine and engineering, on student's motivation, the development of group work skills, information and communication research, and the acquisition of basic knowledge (Neild, T., 2004; Raine & Collett, 2003). In this article, we try to explore the effect of an inquiry-based learning scenario via computer simulation on students' performance in physics and conceptual understanding of temperature and heat.

INQUIRY-BASED LEARNING

From elementary school to high school, new science curricula all over the world now give to so-called active methods, such as Inquiry Based Learning (IBL). The call for inquiry-based learning is based on the conviction that the objective of science learning is no longer the memorization of facts and scientific information, but rather the understanding and application of scientific concepts and methods. This particular emphasis on methods can be traced back to the work of Dewey (1910, 1938). He argued that the development of scientific knowledge occurs through investigation. Consequently, students' attitude toward finding inquiry-based solutions to authentic problems should be encouraged. Dewey's historical notions are in line with current approaches to science learning (Greeno, Collins, & Resnick, 1996; Henning, 2004). From a constructivist perspective, learning aims to overcome what Whitehead (1929) calls "inert knowledge". Knowledge is considered "inert" when there is a lack of knowledge transfer in problem-solving situations that require the use of previously acquired knowledge (Renkl, Mandl, & Gruber, 1996). By investigating complex problems, knowledge can become less inert and more usable (Edelson, 2001). The inquiry-based learning suggests that the student should be seen as an investigator, a seeker of information, and a problem-solver. In this article, the term "inquiry-based learning" is used to describe any type of learning that gives students a high degree of responsibility for the knowledge involved. Students are expected to work independently and build up scientific knowledge by developing their own method and the appropriate approach to solve the problem at hand, taking into account interaction with peers and the teacher. According to Bybee (2019), among the most widely used teaching strategies in inquiry-based learning is the 5E teaching model through a learning cycle (figure1) which consists of five phases: Engage, Explore, Explain, Elaborate and Evaluate (Madu & Amaechi, 2012). In the engagement phase, learners' attention is captured and their prior knowledge is assessed by the teacher, while the exploration part enables learners to engage in a problem-solving investigation. In the explanation phase, the concepts identified by the learners in the exploration part will be reinforced through teacher-led discussion so that learners have a thorough understanding of the concept, while the elaboration part will enable learners to apply the scientific knowledge and concepts they have learned in their everyday lives. The final phase, evaluation, is designed to assess learners' conceptual understanding and progress. This strategy enables learners to generate a conceptual understanding of the subject through investigation and inquiry (Sen & Oskay, 2017) and to construct their own learning through their experiences. Inquiry-based learning allows learners to take control of what they learn in a hands-on activity. One of the new ways of using inquiry-based learning is to use technology via a virtual simulation (Wilson, 2016). In the following section, we identify the contributions and limitations of a computer simulation in science education.

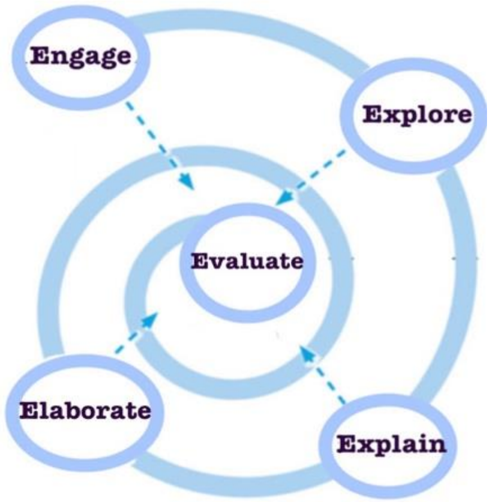

Figure1. Teaching model "5E" (Bybee, 2019)

CONTRIBUTION OF A COMPUTER SIMULATION IN SCIENCE EDUCATION

Virtual simulation is widely used in science education (Droui et al, 2013). It is used as a complementary pedagogical tool alongside hands-on learning activities (Eskrootchi & Oskrochi, 2010). Gredler (2004) lists the main features of a computer simulation:

> *"(a) an adequate model of the complex real-world situation with which the student interacts (referred to as fidelity or validity), (b) a defined role for each participant, with responsibilities and constraints, (c) a data-rich environment that*

permits students to execute a range of strategies, from targeted to "shotgun" decision making, and (d) feedback for participant actions in the form of changes in the problem or situation."

The aim of a simulation is to enable the user to discover for himself the rules underlying the system under study, making them as a very effective "tools for thinking" (Mindtools, see (Jonassen et al, 1999)) from a constructivist point of view:

«An educational simulation should not be the reproduction of a system given to students to digest, but rather given to them so that by exploration and manipulation they can "discover" the system's behavior. » (Winer et Vazquez-Abad, 1981).

Various studies have shown that simulations offer numerous advantages in education, enabling, among other things (Droui& El Hajjami, 2014):

• A concrete representation of concepts, an application of known concepts at higher levels; the discovery of new concepts, new models ;

• Manipulation of virtual objects (Perkins & Simmons, 1988);

• Development of critical thinking skills;

• The identification of cognitive conflict (Osborne & Squires; 1987);

• Simplification of the real systems studied;

• Articulation between a concrete phenomenon and its abstract representation;

• Improved conceptual understanding (Alessi & Trolip ; 1985 ; Windschitl- & Andre, 1998 ; Zietsman & Hewson,1986 ; Droui & al ,2009 ; Droui & al ,2010).

• The activation and development of basic procedural skills (observing, measuring, communicating, classifying, predicting....) (Osborne & Squires ; 1987).

• The activation of procedural skills specifically integrated into the scientific approach (controlling variables, formulating hypotheses, interpreting data, experimenting and formulating models...) (Roth et Roychoudhury ,1993).

• The visualization of phenomena and the multiplication of forms of representation (Richoux et al, 2002 ; Sadler et al,1999). Virtual simulation also presents itself as :

• An alternative to inaccessible experiments (Strauss and Kinzie, 1994);

• A tool for scientific investigation and support for the development of investigative skills (Windschitl, 2000)

• Problem-solving tool (Howse, 1998; Droui et al., 2015);

• Complementary tool to real experiments;

• Support for individualized, need-based learning.

We attempted, through previous studies, to explore the effects of problem-based learning via computer simulation (Droui et al ;2013), and inquiry-based learning via simulation (Droui and El hajjami ; 2013), on conceptual understanding of Newtonian mechanics among Moroccan students in high secondary school. The results showed that students in the experimental group (with API or APP) performed better than those in the control group with a statistically highly significant difference. We wondered whether this difference was due to the inquiry-based approach, to the use of computer simulation, or rather to the combination of both, which led us to this research, which follows on from the previous studies cited above (Droui et al , 2013 ; Droui and El hajjami ; 2013), to study the difference between the three scenarios: 1) Inquiry based learning; 2) Learning via a simulation and 3) Inquiry based learning via a virtual simulation.

OBJECTIF AND RESEARCH QUESTION

The main objective of this study is to examine how an inquiry-based learning scenario, specifically using a computer simulation, affects the comprehension of heat and temperature among

Moroccan middle school students. The study aims to answer the following research question: Does the implementation of an inquiry-based learning scenario, incorporating computer simulation, have an impact on students' performance and conceptual understanding of heat and temperature?

METHODOLOGY

1. SAMPLE AND STUDY DESIGN

This study is quasi-experimental. It includes a pre-test and a post-test. The independent variable in this study was the teaching method used in middle school physics courses. Treatment groups were randomly selected to receive inquiry-based instruction, virtual simulation-based instruction and the combination of an inquiry-based approach and the use of a virtual simulation. The two dependent variables in this study were student performance and conceptual understanding. The sample of the present research consists of two hundred and thirty-four Moroccan middle school students. Each of the students participating in the study was randomly assigned to one of three groups: GVS (n = 78 students) or GAI (n = 78 students), GAISV (n = 78 students). Three physical science teachers took part in the study. The implementation process took four weeks, and the pre-tests and post-tests were administered before the first week of experimentation and after the fourth week, respectively; they were completed by the students in a paper-and-pencil format. To study the effect of inquiry-based learning via a computer simulation, we proceeded to compare the three scenarios: Inquiry-Based Learning (GAI), Simulation-Based Learning (BSV), and Inquiry-Based Learning through Simulation (GAISV) in a physics course at the middle school level.

Both groups (GAI) and (GAISV) received inquiry-based teaching via the "5E"teaching model: Engage, Explore, Explain, Elaborate and Evaluate. The second group (GAISV) received instruction combining inquiry-based teaching and virtual simulation. The first phase “Engage” served as a motivational trigger, and took the form of challenging questions or problems that students had to answer using their pre-existing knowledge. In the phase “Explore”, students in the GAI group carry out real-life activities or experiments that will enable them to identify the concepts being studied. The GAISV group, on the other hand, carry out a pre-simulation activity, during which they explore the navigation process and the functionalities of the virtual simulation. In the phase “Explain”, GAI students explain the concepts in question and discuss them in class without using the simulation. The GAISV group, on the other hand, discusses the concepts in class using the virtual simulation.

In the phase “Elaborate”, the teacher introduces the concept learned by the GAI students in a new context, namely in their daily lives, to give them a broader understanding of the concept, while the teacher presents the problem solved by the GAISV students using special functions of the virtual simulation. The final phase of the discussion was the “Evaluate” stage, during which the teacher had the opportunity to assess the students' learning.

The third group (GSV) learned via virtual simulation. This group begins the learning process with a pre-simulation activity, an orientation activity on how to use the simulation. Class discussion takes place using a series of virtual simulations. Students have the opportunity to answer questions and solve the problem situation using the virtual simulation. Students are also given a post-simulation activity to assess their level of understanding after conducting the experiment using the virtual simulation.

2. TCE TEST AS A MEASURING INSTRUMENT

We will use a test widely employed in physics teaching, the TCE "thermal concept evaluation", It was designed in 2001 by Yeo and Zadnik (2001) at Curtin University in Perth, Australia (Benaliamjoud, Droui and El hajjami, 2014). The TCE test is currently one of the most widely used tools for assessing students' understanding of concepts relating to temperature and heat. The TCE test consists of 26 multiple-choice questions on thermal phenomena observed in everyday situations. This tool has been tested in various countries; in Australia, it was tested with the participation of 478 secondary school students (Yeo and Zadnik, 2001), later the test was used in other countries such as the USA (Luera et al., 2005; Schnittka and Bell, 2011), Turkey (Baser 2006), Libya (Alwan, 2011) and South Korea (Treagust et al., 2012). The TCE as designed by Yeo and Zadnik (2001]) has four main components: the first concerns students' conceptions of heat, the second temperature, the third heat transfer and temperature change, and the last thermal properties of materials. After a highly advanced statistical study of the TCE test, Treagust et al (2012) have retained 19 of the 26 items, grouped into four components: heat transfer and temperature change; boiling; thermal conductivity and equilibrium; freezing and melting.

As public teaching of the physical sciences in Morocco is in French, the original version of the test TCE was translated into French (Benaliamjoud, Droui and El hajjami, 2014). Then, the translation was discussed and validated with five expert middle secondary school teachers (over thirty years of seniority in teaching the physical sciences) and seven university experts (two in educational science, three in the physical sciences and two in chemistry). Following the introduction of the various suggestions, we presented the French version of the test to around twenty students, who found it clear and easy to understand (Benaliamjoud, Droui and El hajjami, 2014). The study of the test's validity and reliability for the research sample is carried out by the researcher (Benaliamjoud, Droui and El hajjami, 2014). The estimated reliability of the Kuder-Richardson 21 (KR-21) test was found to be around 0.71. The data were then analyzed using SPSS 23.0, the statistical analysis software. Means and standard deviations were calculated. An alpha level of 0.01 was used in all analyses.

Subsequently, we administered the post-test to the three groups mentioned above: inquiry-based learning (GAI), learning via computer simulation (GSV), and inquiry-based learning via computer simulation (GAISV). Data were collected from the pre-test and post-test and statistically processed to determine the significant difference in students' performance in learning the physics concept before and after. To analyze the data, the Statistical Package for the Social Sciences (SPSS) was used. Mean and standard deviation were used to determine performance before and after the learning sequences. The pre-test and post-test results of the three groups are then analyzed using a comparative analysis F-test to determine whether there is a significant difference in students' performance in learning the concept of virtual physics.

RESULTS AND DISCUSSION

1. STUDY OF STUDENTS' PERFORMANCE

In physics, students may be able to solve several problems without having a minimum understanding of the underlying physics concepts (Kim and Pak, 2002). Students' conceptual understanding was therefore measured before and after experimentation using the TCE test. Table 1 shows the mean TCE scores of the three groups: GAISV, GAI, GSV summarizes the descriptive statistics of the scores obtained (dependent variable) between pre-test and post-test. Conceptual learning results were also analyzed by comparing pre- and post-test scores. To avoid "ceiling" or "floor" effects, conceptual gains were normalized and compared. Normalized gains (Hake, 1998)] are defined as follows: g = gross gain / maximum possible gain = (Post T - Pre T) / (max T - Pre T). This measure gives the ratio of the gross conceptual gain (post-test and pre-test) obtained to the maximum possible gain. For example, a gain of 0.4 means that 40% of the remaining concepts to be learned were acquired by the end of the course. Normalized gain is the measure most frequently used to report conceptual test results.

Table 1. The mean TCE scores of the three groups: GAISV, GAI, GSV between pre-test and post-test

	GAISV	GAI	GSV
Pre-Test	7,35	7,53	6,9
Post-Test	13,35	12,1	8,9
Difference	6	4,57	2
Gain Hake	47%	37%	15%

We note that the average score obtained by the GAI group rose from 7.53 (with a standard deviation of 3.37 at the 1% significance level) to 12.1, showing an improvement of 4.57, the average score of the GSV group also increases from 6.9 to 8.9, showing an improvement of 2, while the average percentage of correct answers for the GAISV group rose from 7.35 to 13.35, showing an improvement of 6. We used ANOVA to detect significant differences between the results of the groups (GAISV, GAI, GSV). Before examining the results of the ANOVA, it is important to check the premise of equality of variances with Levene's test.

Table 2. Homogeneity of variances Test

	Levene's statistic	ddl1	ddl2	Sig.
Based on Average	1,179	2	231	,319

In this example, as the test is not significant (p =0.319> 0.01), we cannot reject the null hypothesis of equality of variances. They are therefore considered similar, which suits us perfectly and allows us to move on to the ANOVA interpretation.

Table 3. ANOVA results (pretest)

	Sum of squares	ddl	Mean square	F	Sig.
Inter-groups	16,427	2	8,213	1,488	0,228
Intra-groups	1275,120	231	5,520		
Total	2096,850	233			

The F statistic is 1.488, and the probability of finding this F value -when the null hypothesis (0.228) is true- is greater than 0.0001. Therefore, we cannot reject the null hypothesis and say that there is no significant difference in the pre-test scores of the three groups.

Table 4. ANOVA results (postest)

	Sum of squares	ddl	Mean square	F	Sig.
Inter-groups	821,730	2	410,865	74,432	,000
Intra-groups	1275,120	231	5,520		
Total	2096,850	233			

The F statistic is 74.432, and the probability of finding this value of F -when the null hypothesis is true- is smaller than 0.0001, showing less than 0.01%. So, we have sufficient evidence to reject the null hypothesis and say that it is unlikely that the difference in scores obtained for the three groups is the same. These results show that, even if no significant difference existed between the three groups before teaching, the three groups obtained more significantly different gains after experimentation. We find that the normalized learning gain for all questions, according to Hake's indications, corresponds to a medium and moderate improvement in the average normalized learning gain for the GAISV (0.47) and GAI (0.37) groups, and a qualified level gain for the GSV group (0.15). Table 5 shows the results of multiple comparisons of the mean differences between the three groups. A multiple performance comparison shows that the gains between the three groups (1,43, 2.57 and 4) are significantly different (at 1%).

Table 5. The differences between the average performance of the three groups

Variables	Mean Difference	T	p -value	Comments
GAISV vs GAI	1.43	1,892	< 0.0001	Significant différence at 1%
GAI vs GSV	2,57	1,975	<0.0001	Significant différence at 1%
GAISV vs GSV	4	1,875	< 0.0001	Significant différence at 1%

2. STUDENTS' CONCEPTUAL UNDERSTANDING OF HEAT AND TEMPERATURE

We will present the results of this study according to the four components of the TCE test. The TCE Test, designed by Yeo and Zadnik (2001), has four main components: the first concerns students' conceptions of heat, the second temperature, the third heat transfer and temperature change, and the last thermal properties of materials. After a highly advanced statistical study of the TCE test, Treagust et al. (2012), retained 19 items from the 26; these items are grouped according to four components: heat transfer and temperature change; boiling; thermal conductivity and equilibrium; freezing and melting.

Table 6. The four conceptual components of TCE test

Components	Corresponding items
Heat transfer and temperature change	item 7, item 10, item 13, item 15, item 22, item 23 et item 25
Boiling	item 4, item 5 et item 6
Thermal conductivity and balance	item 14, item 16, item 17, item 18, item 24 et item 26
Freezing and melting	item 1, item 2, item 11

2.1. STUDENTS' CONCEPTUAL UNDERSTANDING OF HEAT AND TEMPERATURE

The first component of the TCE test consists of the following items: item 7, item10, item 13, item 15, item 22, item 23 and item 25.

Students were generally confused about the concepts of heat and temperature. Table 7 shows the percentages of correct answers to the items (pre-test and post-test) relating to the "Heat transfer and temperature change" component. The results are positive for GAISV, with the percentage of correct answers to all items exceeding 50%. However, we note negative results (percentages of correct answers below 50%) for the GAI (items 13 and 15) and for the GSV (items 13,15,2 3,25).

Table 7. Percentages of responses to items related to «the Heat Transfer and Temperature Change component».

Item	7		10		13		15		22		23		25	
	BE	AE	BE	AE	BE	AE	BE	AE	BE	AE	BE	AE	BE	AE
GAI	47	70	46	69	24	47	2 3	46	61	84	39	62	41	64
GAISV	46	76	45	75	23	53	22	52	60	90	38	68	40	70
GSV	44	54	43	53	21	31	20	30	58	68	36	46	38	48
BE: Before the experiment								AE : After the experiment						

2.2. BOILING

The context of the three items (item 4, item 5, item 6) making up this component was boiling water in a pot. Table 8 shows the percentages of correct responses to items relating to the "Boiling" component. The results are positive for GAISV; the percentages of correct answers to all items exceed 50%, and more than half the students in the GAISV group indicate that the temperature at the boiling point does not remain constant and that the steam in the kettle is over 100°C (see Table 8). The majority of students are familiar with this type of situation. However, students in both the GAI and GSV groups recorded negative results, with percentages of correct answers below 50% for both groups and for all 3 items.

Table 8. Percentages of responses to items related to the component "Boiling"

Item	4		5		6	
	BE	AE	BE	AE	BE	AE
IBL	21	44	22	45	23	46
IBLVS	20	50	21	51	22	52
LVS	18	28	19	29	20	30
BE: Before the experiment			AE : After the experiment			

2.3. HEAT CONDUCTIVITY AND EQUILIBRIUM

The elements of this component (item14, item16, item17, item18, item24, item26) involve experiments related to phenomena encountered in everyday life. Students are required to apply the concept of heat conductivity between two materials at different temperatures until a state of equilibrium is reached. Students should also be aware that different materials have different heat conductivities, even if they are in a state of equilibrium at the same temperature. Table 9 shows the percentages of correct answers to the items (pre-test and post-test) relating to the "Heat conductivity and equilibrium" component. The results are positive for GAISV, with the percentage of correct answers to all items exceeding 50%. However, we note negative results (percentages of correct answers below 50%) for the GAI (items 14-16) and for the GSV (items 14-17,26).

Table 9: Percentages of responses to items related to the component "Heat conductivity and equilibrium"

Item	14		16		17		15		24		26	
	BE	AE	BE	AE	BE	AE	BE	AE	BE	AE	BE	AE
GAI	21	44	23	46	39	62	23	46	50	73	39	62
GAISV	20	50	22	52	38	68	22	52	49	79	38	68
GSV	18	28	20	30	36	46	20	46	47	57	36	46
BE: Before the experiment							AE: After the experiment					

1.1. FREEZING AND MELTING

In this component, the items talk about blocks of ice in the freezer (item 1), blocks of ice in water (item 2) and ice and water both at 0°C in the freezer (item 11). This component is then linked to basic concepts of thermal physics, yet only 46% of students indicated that ice always remains at 0°C and 31% of students suggested that water cannot be at 0°C.

Table 10: Percentages of correct answers from the three groups on items related to the component "Freezing and melting"

Item	1		2		11	
	BE	AE	BE	AE	BE	AE
GAI	33	56	54	77	49	72
GAISV	32	62	53	83	48	78
GSV	30	40	51	61	46	72
BE: Before the experiment			AE: After the experiment			

Table 10 shows the percentages of correct answers to the items (pre-test and post-test) relating to the "Freezing and Melting" component. We record positive results for the GAISV and GAI; the percentages of correct answers to all items exceed 50%. However, we note negative results for the GSV (items 1): percentages of correct answers below 50%. In sum, the results show an improvement in performance and conceptual understanding of heat and temperature among Moroccan high school students. For all three groups: GAISV, GAI and GSV. An approach based on a combination of inquiry and virtual simulation seems promising for learning about heat and temperature at secondary school level. Indeed, the IBLVS recorded better results than the IBL and LVS groups.

CONCLUSION

In conclusion, this study has revealed positive results supporting on the one hand the findings of previous studies (Mazur, 1997; Hake, 1998). on the other hand, the results are significant for the study of the effectiveness of the inquiry-based approach on the conceptual understanding of the concepts of temperature and heat. Thanks to its appeal, we believe that the inquiry-based learning method could smoothly change the way teachers and students perceive teaching. Following the results of this study, students who participated in inquiry-based teaching, virtual simulation and inquiry-based teaching via virtual simulation showed a clear improvement in their performance between post-test and pre-test. Comparing the overall performance of the three groups, this study reveals that inquiry-based learning through virtual simulation has a more significant effect on students' conceptual understanding of temperature and heat concepts, and on their performance, than inquiry-based learning without simulation, in turn, records significantly better results than learning solely via simulations. According to the results of this research, it's the combination of the use of technology (simulation in this research) and the choice of an appropriate active learning approach (active learning in this research) that can optimize the learning gain in terms of students' conceptual understanding and performance.

In short, digital technologies offer us both technological opportunities and pedagogical challenges: Opportunities to radically change the ways that facilitate learning (Droui et al. 2013) and to "rethink, relocate, in space and time, exchanges between teachers and students, and thus foster new avenues for learning or training activities" (Karsenti , Depover, and Komis, 2007); Challenges in discovering how to build and deploy learning support environments.

Computer simulation can be seen as a support for new activities in science education: the emphasis is on model manipulation, the interplay of representations, both graphical and mental, the visualization of scientific phenomena and the construction of scientific models. This study has shown that simulation is a powerful tool that could be very beneficial to learning. The learning gain will be even greater and more significant if the use of simulation is adopted according to a more appropriate learning approach centered on the needs of learners and integrating technologies at the right time and for the right activity.

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