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Discrete event simulation to build simulators for teaching

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Recent studies propose the use of discrete event simulation models as a tool to help teaching. That is suggested mainly due to the current development of software and its visual animation resources. Therefore, this paper presents simulation models to assist teaching in high school classes. The models were used to analyse the concepts of switching time and also reflection and refraction of light. Three types of comparisons were performed to evaluate the models. First, with other existing simulators; second, according to the grades of students who used the simulator developed; and third, with students who have not used this teaching resource. The results looked promising and showed that there is potential for the use of simulation as additional resources in classes.
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1. Introduction

As mentioned by Goldsman *et al* (2010), several examples and combinations involving simulation applications can be found throughout history. However, according to White and Ingalls (2009), the application of simulation is usually seen into two fields. First, as training environment of specific skills or learning of systems with operational risk, having as the most typical case the training of airline pilots. Second, as an analysis tool for systems and processes. The second application is the one that usually designers and researchers use in search of problems solving and analysis of a given system or process already existing or by being deployed.

Kincaid and Westerlund (2009) point out that, besides the applications mentioned, simulation can be used for all levels of teaching. In the recent work of Silva and Rangel (2011), it was demonstrated that the environments of discrete event simulation (DES) can be used in the development of simulators for teaching purposes, like general purpose programming language. These studies have proposed an alternative to build simulators for teaching aid (so-called educational kits simulation) in a relatively simple way. In this manner, instead of using commercial and series 'teaching kits' to assist learning, teachers can build their own simulators 'customized'. That is, a teacher, with training in one of the software of DES development, can build his teaching kits for his needs. In addition, Sargent (2013) points out that the use of simulation environments, with specific programming language, often results in models with more visual flexibility and fewer errors than a general purpose programming language.

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From the viewpoint of visual animation system, which is what matters in these situations, the use of a discrete simulation environment is quite easy to learn. Moreover, assuming that the teacher already knows the concepts related to the items to be taught, he can develop simulation models according to their complexity. The examples presented in the work of Silva and Rangel (2011) were made using the free version of the software, thus demonstrating the potential development of these environments also for this purpose.

This study aimed for the construction and evaluation of two simulation models to be used as teaching resources for high school classes. The models were constructed using commercial software in its free version. This software, typically used to build DES models, was utilized in order to develop models to analyse concepts to be used in classes of a technical course of Telecommunication and Physics. The main reasons that motivated the proposed application are the cost of teaching simulators and the possibility of assisting practical classes. In other words, the proposal raised is that the teacher himself elaborates his simulator to be used as a teaching resource in his classes the same way he uses other software to build spreadsheets or text editors.

2. DES software

A simulation model can be built with general purpose software, simulation languages and simulation environments. Pidd (2004) explains that the environments of DES differ from general purpose languages, such as C, C++ or Java, as well as simulation languages like GPSS or SIMAN. In a DES environment, the developer usually does not need to enter lines of code during the construction of his models. Also, it does not require in-depth knowledge in a programming language. According to Law (2007), these environments offer a range of resources to the development of simulation projects and resources that allow the construction of its animated simulation models. With these facilities, it is possible to construct a simulation model with animation quickly and safely. It can also be considered the inclusion of numerous details and information regarding the system analysis. The use of additional resources such as charts, displays, metres, moving machinery, parts and people, and so on can be given as examples.

In addition, Banks *et al* (2009) attributed the improvement of the graphical interface and the appearance of animation as one of the biggest advances in simulation software since its creation.

Thus, two significant contributions, which can be applied to the educational field using the simulation software, are highlighted. First, the addition of a large number of users, who are not specialists in computer programming, can build simulation models. This allows, for example, a teacher to create his own models with essential knowledge of simulation. Second, the simulated training systems, developed with general purpose programming language, require a relative high time and, of course, an expert developer to build the simulator. However, the models developed in an environment of DES are built in a shorter time. This happens with basic knowledge of programming. That is, in general, a teacher can make his lessons more dynamic (or more productive) by using simulation models to represent certain concepts to be explained.

Robinson (2004) also highlights, as a progress of simulation software, the possibility of exchanging information with other applications, for example, spreadsheets. Thus, this feature allows the student to interact with simulated models. In other words, the student, with the aid of a spreadsheet, can modify the settings of the model, previously designed and configured by the teacher, and analyse the effects of these changes by viewing the animations. This level of interactivity, besides being able to make lessons more attractive, also allows the demonstration of more concepts and other examples of the topics taught.

3. Simulation in teaching activities

Hoffler and Leutner (2007), in their study, concluded that there is evidence that, in the learning process, animations are more efficient in still images. According to the authors, this occurs when the viewing of a movement represented in the animation of a simulator explicitly refers to the subject to be learned. In other words, the observation of an animated simulation, by a student, can play a role in achieving the concepts to be learned. Consequently, this facilitates the absorption of the information transmitted by the teacher. Thus, the construction, for example, of models of DES as teaching resources is a possibility that appears as a learning tool.

Some researchers have shown interest in studying the application of DES as a teaching and training resource. In Computer Science, Nugroho and Suhartanto (2010) proposed the use of DES to teach concepts of computer networks. Garrido and Bandyopadhyay (2009) used the DES to create models to educate and train students and professionals who work with information security. Christou *et al* (2007) related the DES to the creation of experiments that help the study of computers networks sensors.

In the field of Production Engineering, Martinez and Canãdas (2010) presented a new application for teaching manufacturing systems. Van der Zee and Slomp (2005) illustrated how simulation and games can be used to support lean manufacturing systems. Adams *et al* (2005) proposed to improve the learning process of the student in the principles of supply chain management. In Smeds (2003), a method to accelerate learning at industrial management has been presented.

For the development of teaching models using DES, three aspects need to be considered:

- with how many graphic resources the environment of simulation can contribute to and facilitate the development of the simulation project;
- the choice of simulation software that is suited to the needs and profile of the developer; and
- how much of visual interactivity and manipulation by users of simulation models is needed so that the main objective of the lesson takes place.

It should be clear that a teaching simulator is not a typical model of simulation. Namely, for the development of a simulation model, the designer usually follows a methodology that includes the system description; construction of the conceptual model; implementation, verification and validation; design of experiments; statistical analysis of results; among other general steps in the design of simulation.

On the other hand, in an educational simulation, the developer is interested in building a lively atmosphere in computer for the representation of concepts to be taught. That is, the statistical results are less valuable than the visual result of the animation of the simulation model.

4. Construction of didactic simulators

This paper features two selected examples to illustrate the possibility to build simulation models to support classes in high school with DES software. The first simulator was elaborated for a lesson of Telecommunication technical course, of which topic was the Switching Time. The other simulator was developed for a lesson of Physics with the related topic Reflection and Refraction of Light.

The models are constructed by teachers of Telephony and Physics with basic knowledge of simulation and pursue the following steps:

- development of conceptual models related to systems, where the concepts of the chosen interest topics could be addressed in a class;
- construction of the communication interface in a spreadsheet, where the teacher and the student can change model parameters and observe examples of the subject;

- computational implementation of simulation models with their respective animations; and
- verification and validation of simulation models.

It is worth mentioning that the different concepts of digital telecommunication often show discrete nature due to the type of signal that travels by digital systems. Therefore, the topics used for the development of the model proposed in Example 1 and their animations can be applied to other types of systems related to digital communication such as data communications. In Example 2, although the light is a phenomenon of continuous nature, the basic concepts of reflection and refraction could be represented in the discrete simulation model, where the entity of the model was the light wave.

The simulation models developed in this work were constructed using the Arena software (Kelton *et al*, 2007). The Microsoft Excel software was also applied in building spreadsheets, which are used as an element of interactivity between the student and the simulation models.

The models are relatively simple and can be run in the academic version. That version is free of charge, and allows students to use the didactic models even with the restrictions of this version of the software.

For the practical use of simulators proposed, the student must only utilize the configuration interface of the spreadsheet model. This interface was previously configured by the teacher in order to be able to test different scenarios (or ‘samples’) of the present study.

It is important to emphasize that the models were developed by the teacher of the subject after having conducted training of 20 hours with the software DES.

Thus, once the teacher himself is the modeller, he can make changes, adapting the model to the needs required to facilitate the exemplification of the concepts to be covered in classes. The fact that the teacher himself elaborates models means that he used the software to build simulation models as application usually adopted in day-to-day life.

4.1. Example 1—switching time class

In Telecommunication, a switching time permits a package of digital information to change its position within a time interval, allowing being delivered in a different position from where it was originated. This is possible using a memory of writing and reading.

Thus, an input channel can communicate with any output channel according to the needs of communication.

Figure 1 shows the spreadsheet for configuration of the switching time simulator. The student can set the order of their own writing.

The topics covered by this simulator are:

- basic concept of switching time;
- switching time with cyclical writing and random reading; and
- switching time with random writing and cyclical reading.

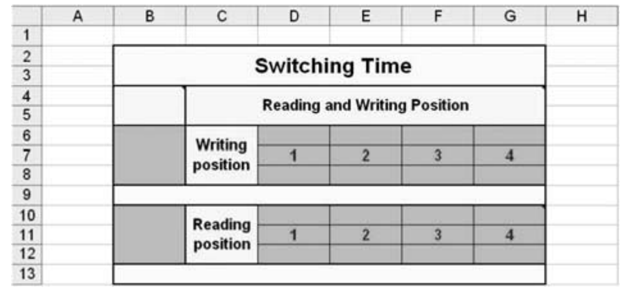

Figure 1 Interface for configuration of the switching time simulator.

The spreadsheet corresponds to memory address information in this simulator, and the student can set the order of the own writing and reading. In the example shown in Figure 1, the memory of the switching is set to write in the addresses from 1 to 4 and read in the same order, that is, in the addresses from 1 to 4.

At the switching time for writing cyclical and random reading, the student must set up the spreadsheet with addresses of writing, in a row, from 1 to 4 and reading addresses also in a row so that he can choose within that range. Figure 2(a) shows a time of this switching time. In the switching time for random writing and cyclical reading, the student must configure addresses of writing in any desired order and addresses of reading in a row from 1 to 4. Figure 2(b) shows a moment of that switching time.

It can be seen in Figures 2(a) and (b) that the two switching time methods used allow changing of the position of the output information regarding the entrance. According to this, the student can see, through the simulated model, actions of the system that would usually be addressed by the teacher only in a theoretical way, facilitating, thus, the understanding of the concept.

4.2. Comparison among simulators—Example 1

In Telecommunication area, the segment of digital communication, whether for voice traffic or data, has the feature of discrete systems in many of the concepts, so this facilitates the use of DES environments. Therefore, this section has two objectives: the comparison of simulators developed in this work with other simulators also used to teach classes in digital telephony; and the comparison among the proposed simulator and other simulators used for analysis of digital communication systems.

Table 1 shows a brief comparison between the proposed simulation models and the simulation software for digital telephony used in Telecommunication courses. The comparison aimed for verifying the ease of access to the simulator, necessary requirements for the use of simulation software and the key features, and additional facilities offered by the compared environments.

The main advantage of the simulation models proposed by the study in relation to the simulator of digital telephony, usually used in Telecommunication courses, is the possibility of

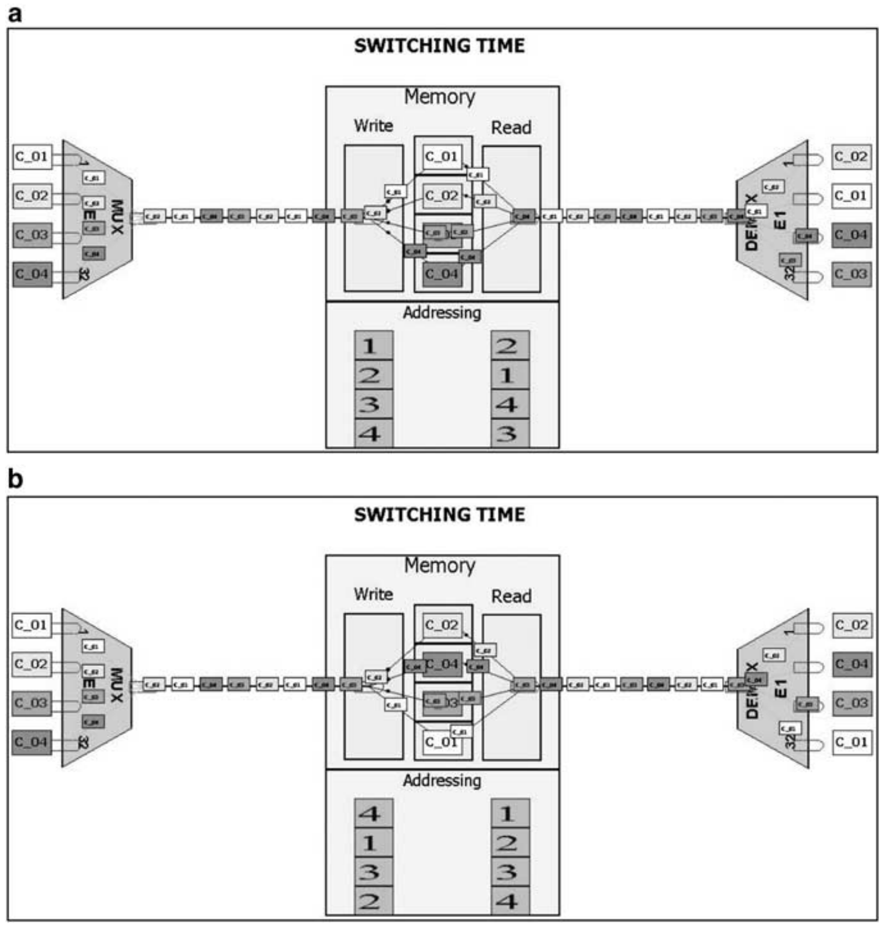

Figure 2 Moments of the animation of the switching time simulator: (a) Cyclical writing and random reading; (b) random writing and cyclical reading.

Table 1 Comparison between standard simulators and simulators built in ARENA

Characteristics	*Digital telephony simulators*	*Proposed simulation with Arena*
Requirement	Simulator (CD ROM)	Arena Software
Licence	Yes	Free Version
Interactive model	Yes	Yes
Allow change	No	Yes
Additional resources	No	Yes
Adjust viewing	No	Yes

modifying the parameters of the models. This allows the demonstration of scenarios of atypical transmission, such as the introduction of the noise element in the transmission line or loss of synchronization and verification of these effects on the quality of the received signal. As an additional advantage of the proposed models, there is the possibility of the use of models, by students, in an extra-class environment due to the usage only of the free version of the simulator in the Arena for the construction of the simulators.

Table 2 shows the comparison among the Arena simulation environment and two discrete event simulators used for simulation of digital communication systems, which are the Optnet and the NS-3. The comparison aimed for the analysis of aspects such as ease of access to the simulator, project development, and programming and configuration models. Additional resources offered and applicability of the simulator were also considered in the comparison.

The Optnet is a computational tool used to optimize cost, performance and availability of computer networks. It has a user-friendly, well-developed graphical interface. The NS-3 is an open source discrete event network simulator mainly directed to research and educational use. For developments of simulators in NS-3, the models must be written in C++ or Python.

The three simulators are easily found on their Web pages. In relation to items of comparison, the main advantage demonstrated by the simulators developed for didactic use in the Arena is the animation resource well developed and the easy use compared with simulators based on a programming language.

Table 2 Comparison among simulators

Characteristics	*Optnet*	*NS-3*	*Arena*
Requirement	Programming basic notion *	C++ or Phyton	Programming basic notion *
Licence	Academic version	Open-source	Free version
Animation	No	No	Yes
Allow change	Yes	Yes	Yes
Additional resources	Yes	Yes	Yes
Graphics	Yes	Yes	Yes
Ease of use	Moderate	Difficult	Moderate
Didactic application	Appropriate	No appropriate	Appropriate

*Person not specialized in computer programming, only user.

Simulators of digital communication based on Optnet are perfect for checking network performance and analysis of different scenarios, besides presenting graphical information resources of a very wide configuration. However, this simulator did not include any visual animation that could satisfy the objective of this study, that is, an illustration of digital communication concepts through animated models.

The NS-3, as disadvantage, needs the developer to have deeper knowledge in programming language, which, for the purpose of this study, would not make viable the construction of didactic models for some teachers. In this sense, the construction of models based on the Arena simulation environment stands for the relative ease of configuration of models.

4.3. Evaluation of simulator in classes—Example 1

The purpose of this section was to prepare an initial statistical analysis for verification of acceptance and contribution that the didactic simulation models gave to the students of Technical Telecommunication. The evaluation was conducted in a Telecommunication technician course (intermediate) from an institution of the Brazilian Federal Government.

For initial analysis of the didactic models developed, an assessment, to the content of the discipline of Digital Telephony on three classes, was applied. The number of participants was 45 students. The issues addressed in the assessment were similar to tests applied to previous classes that did not use simulation didactic models. The average grades obtained by the group that had access to the simulator (Group B) were compared with grades of the historical series consisted of six groups (Group A). The results are presented in the Table 3.

Each group was subdivided into five categories relating to the ranges of values of the coefficient of efficiency (CE) of students in the Telecommunication technical course. Table 3 presents the average grade of each group in each category, besides the difference of the average grade between Groups B and A, and also the percentage increase of grade in each category.

Table 3 Percentage of increase in grade by category

Category	*Average grade of Group A*	*Average grade of Group B*	*Average increase of the grade by category*	*Percentage of increase in grade by category*
CE ⩽ 7	5.94	6.90	0.96	16.24
7 ⩽ CE ⩽ 7.5	6.66	8.10	1.43	21.53
7.5 ⩽ CE < 8	7.58	8.90	1.32	17.46
8 ⩽ CE ⩽ 8.5	8.09	9.48	1.40	17.26
CE ⩾ 8.5	8.56	9.14	0.58	6.78

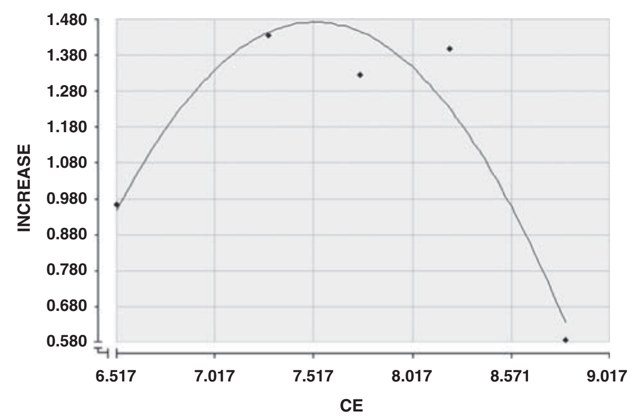

Figure 3 Percentage graph of increase of grade by category. *Note*: The scale does not start at number 0. In other words, there is increase in all points.

Note, by the values presented in Table 3, that all categories for Group B had an increase in their average grades when compared with their respective categories in Group A. The category of students with the highest percentage, however, increase in average test grades was with CE between 7 and 7.5. In this category, 21.53% of students had improved their grades compared with students of the same category of the group that did not have access to the simulator. Figure 3 shows the same information for a coefficient of determination (R^2) of 91.40%.

Table 4 shows the average grade of students by age group within each study group. It can be observed that there was no significant statistical difference among younger and older students when compared within the same group. Likewise, there was no significant statistical increase among older students (21–30 years) in Group B when compared with students of the corresponding Group A; however, there was significant statistical increase of the average grade for the younger students (up to 20 years) when the simulators were used in class. It is essential to highlight that in all comparisons made, if the averages were followed by the same letter, uppercase vertically and lowercase horizontally, they do not differ significantly from each other, at level of 5% probability by the Student's *t* test.

Table 5 presents the average grade of students divided by where they attended high school, comparing them in each study group. It can be seen that there is significant statistical difference in average grade among students who attended high school at the same institution (School A) and those who attended at another school (School B), within the study group A. This difference is not observed in the study group B. When compared the study groups A and B, Table 5 shows that students who attended high school in another school (School B) and used the simulators had a significant statistical increase in their average grades when compared with students who attended high school in the same School B and who did not use this educational resource. The comparison between Groups A and B of the students who attended high school at School A showed no significant statistical increase of the average grades.

Conclusions extracted from the analysis of Table 5 show that didactic resources based on simulation can function as a leveler element for students who had a different mid-level training and joined in a course of Telecommunication technical training. However, more detailed analysis about this conclusion was not performed since this was not the focus of the study.

Figure 4 shows the comparison chart between Groups A and B considering the profile of students in the categories gender, age and local training high school. It can be seen the average grades and their standard errors in each category analysed. As shown in Table 5, the largest difference in average grades between Groups A and B is in the students who attended high school in other schools than School A. In this category, students belonging to Group A had an average grade of 7.07 and students of Group B, average grade of 8.47. Figure 4 also confirms the conclusion shown in Table 3, that is, there was an increase of the average grades in all categories of Group B in relation to Group A.

Figure 5 shows the comparison between the categories within the study Group B that used the simulation models proposed. The values correspond to an average increase of students' grades when compared with students of the corresponding categories of Group A. Considering this comparison, it is possible to observe that students who attended high school in other schools were those who had greater average increase in their grades: 1.339. This occurred as shown in Table 5 because these students were those with the lowest average grade: 7.074.

As shown in Figure 4, the average grade in the study group B, in the high school category, was 8.41 and 8.47, respectively, for students who attended high school in Schools A and B. In Figure 5, for these students, the average increase was 1.399 and 0.457, respectively. Therefore, it is concluded that the use of didactic simulators, as educational support for digital communication teaching, shows potential to be utilized as a tool for levelling among students from different backgrounds. This could be interpreted as bringing the weaker students to near the better ones.

Table 4 Comparison among age groups

Age group	*Without resource (Group A)*	*With resource (Group B)*
Up to 20	7.244 ± 0.197 Ab	8.387 ± 0.246 Aa
21–30	7.784 ± 0.278 Aa	8.571 ± 0.391 Aa

Table 5 Comparison among the students concerning where they attended high school

High school	*Without resource (Group A)*	*With resource (Group B)*
School A	7.956 ± 0.259 Aa	8.413 ± 0.363 Aa
School B	7.074 ± 0.199 Bb	8.473 ± 0.255 Aa

4.4. Example 2—model for physics class

This simulator discusses simple concepts of geometric optics, in this case, law of refraction or Snell's law, shown in Equation (1). This law expresses the path difference in terms of the projection angle of light rays and its relation to the indices of refraction for each medium, N_1 and N_2, and θ_1 and θ_2, respectively.

$$N_1 \, sen\, \theta_1 = N_2 \, sen\, \theta_2 \qquad (1)$$

As shown in Equation (2), the refractive index of a medium is defined as a relation between the propagation velocity in a vacuum and the velocity of propagation in that environment.

$$N_{medium} = \frac{V_{vacuum}}{V_{medium}} \text{ where } V_{vacuum} = 3 \cdot 10^8 m/s \qquad (2)$$

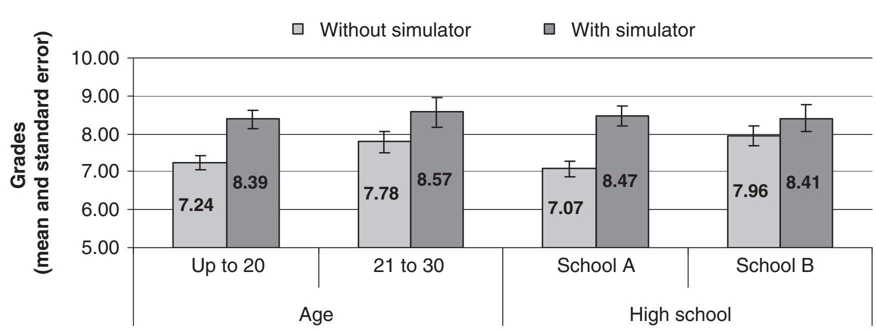

Figure 4 Comparison among students who used and did not use the simulators.

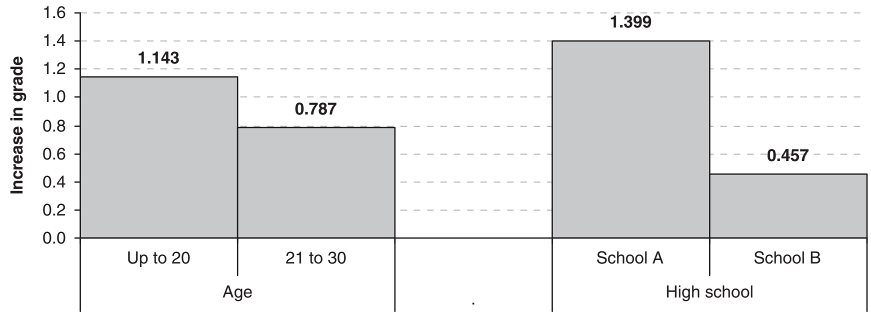

Figure 5 Increase in grade.

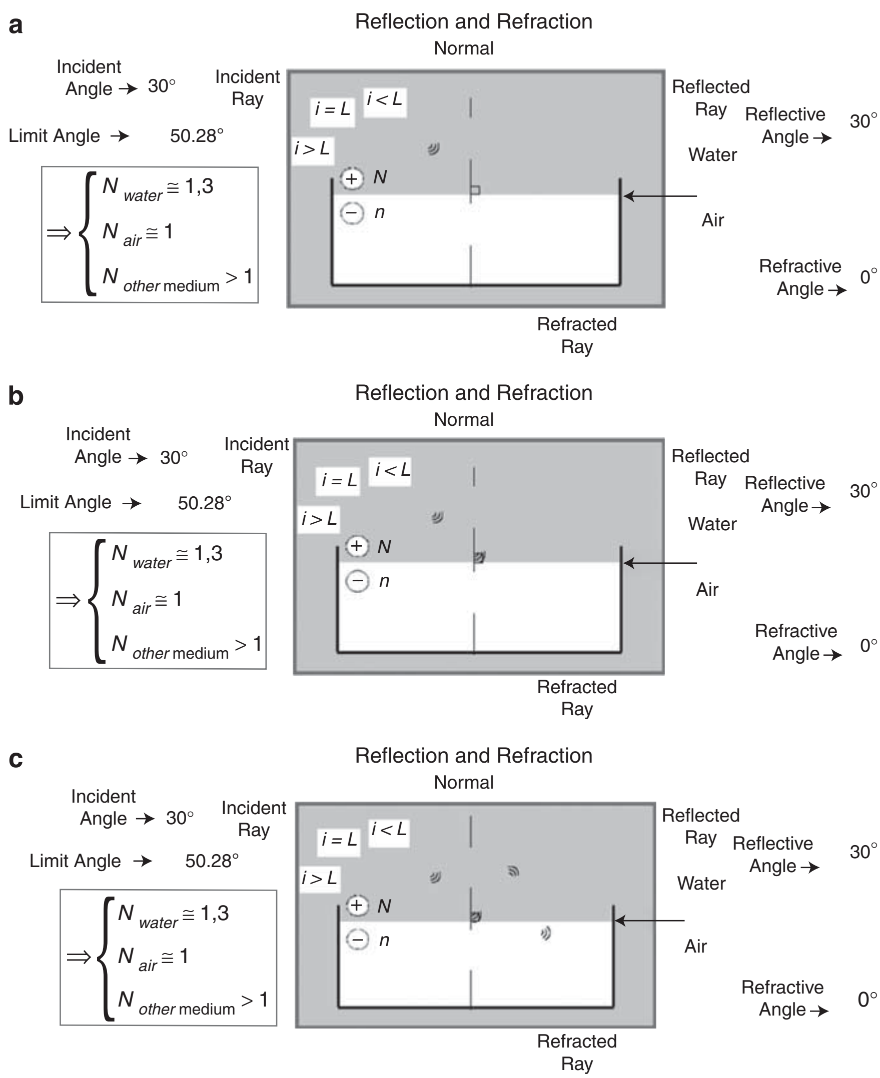

Figure 6 Different moments of execution of the simulation model. (a) Reflection and refraction – moment 1; (b) reflection and refraction-moment 2; (c) reflection and refraction – moment 3.

Figures 6 (a)–(c) presents three instants of operation of the simulation. The example shows the path of light when spreading from water to air.

In addition to designing the trajectory and indicating the preset limit angle, the simulation shows the angle of reflection and refraction depending on the angle of incidence chosen (Figure 6 (a)). As the selected angle was of 30° (angle of incidence smaller than the limit angle), the reflection angle is of 30° (Figure 6(b)) and the refraction of 41° (Figure 6(c)). The student may also choose other values for the angle of incidence. Depending on its ranking (smaller, equal to or larger than the limit angle), the ray goes through a different path, varying, as a consequence, the angles of reflection and refraction.

4.5. Comparison between simulators—Example 2

A comparison was made between the simulator developed in this study, shown in Figure 6, and another one with similar purpose. In this case, the PhET (Physics Education Technology) simulator was chosen. The PhET provides free interactive simulations of physical phenomena and can be accessed, freely, at http://phet.colorado.edu.

The PhET simulator offers the option of choosing angles, materials and indices of refraction. Also, it allows viewing angles using a protractor, as well as seeing the propagation of the light wave, altering its speed. Table 6 shows the results of a qualitative assessment of both.

The simulator found in the PhET is complete and offers more features than the one developed in Arena. This model was developed by programmers in Java language, requiring advanced knowledge in this programming language for making similar models. The model made in the simulation environment Arena, despite having a lower level of detail, is appropriate to the real needs of the classroom. If there is a desire to implement future changes, the teacher himself may make them as he is the developer of the discipline.

Analysing the application of DES software in the two examples presented above (Examples 1 and 2), it appears that, in both cases, the use of Arena allowed the teacher himself to prepare, in an easy and fast way, a simulation model according to the need of the class.

4.6. Evaluation of simulator in classes—Example 2

The evaluation of the simulator was conducted in the specific Physics class about it. The evaluation was followed, by a statistical analysis, to verify the gain obtained with the use of the resource in class.

Table 6 Comparison between the PhET simulator and the simulator built in Arena

Characteristics	*PhET Simulator*	*Simulator in DES environment*
Development environment	Java	ARENA
developer	Programmer	Teacher of the discipline
Licence	No	No (free version)
Interactivity	Yes	Yes
Allow change	No	Yes
Dynamic model	Yes	Yes
Adjustment of visualization	No	Yes
Degree of detail	Bigger	Smaller
Development time	50–60 hours*	7 hours

*Estimated time for an experienced programmer with Java.

It was performed in three groups of the last year of Brazilian high school, that is, the last year before entering university. The sample evaluated was of 98 students from two different public schools, both located in the peripheral area of a city in the countryside of Rio de Janeiro State, Brazil. In the first school, a class of 24 students was evaluated. In the second, two classes of 37 students each were analysed. Each class was divided into four equal groups and each one was evaluated separately.

Table 7 presents the design of experiments performed with the classes.

The questionnaire had different levels of resolution, two easy, two medium and two difficult. The easy ones approach more intuitive concepts. Medium questions have deeper concepts. A question is about reflexion, and the other one, about the relation between the angles of reflection and refraction. The questions considered difficult ask about the index of refraction. Both considered the hardest ones show a figure and question about the refractive index of the two surfaces shown by the image.

Each group was divided into four groups of students (A, B, C and D) as shown in Table 7. In Group A, only the questionnaire was applied without any prior exposure. In Group B, the content of the theoretical classes was presented, and later, the questionnaire was applied. In Group C, only the simulator was presented, and, soon after, the questionnaire was answered by students. In Group D, the class was exposed to the theoretical subject followed by the use of the simulator as a resource for teaching help. After this exposure, the questionnaire was also applied.

With this structure of experimentation, it was possible to see, through statistical analysis, the influence or not of the theoretical class and the simulator together onto the correct answers of the different levels of the questions presented.

Then, the results were analysed using logistic regression, obtaining odds ratio, which allowed identifying how many more chances a student, that had access to a given teaching resource, has to answer a question in relation to the private student of this resource.

The execution time was adjusted in relation to the initialization of the physical phenomenon. It was not important to have any timing compatibility between the simulation time and the clock time.

The results obtained after the statistical analysis performed with the questionnaires are shown in Figures 7 and 8.

Figure 7 shows the result of statistical analysis. The conclusions were presented following the design of the experiment (Table 7). The control (contr.) shows the group that uses no resources, neither in the theoretical class nor in the simulator.

Table 7 Experiments to evaluate the simulator in classroom

Groups of students	*Class with no simulator*	*Class with simulator*
A	No	No
B	Yes	No
C	No	Yes
D	Yes	Yes

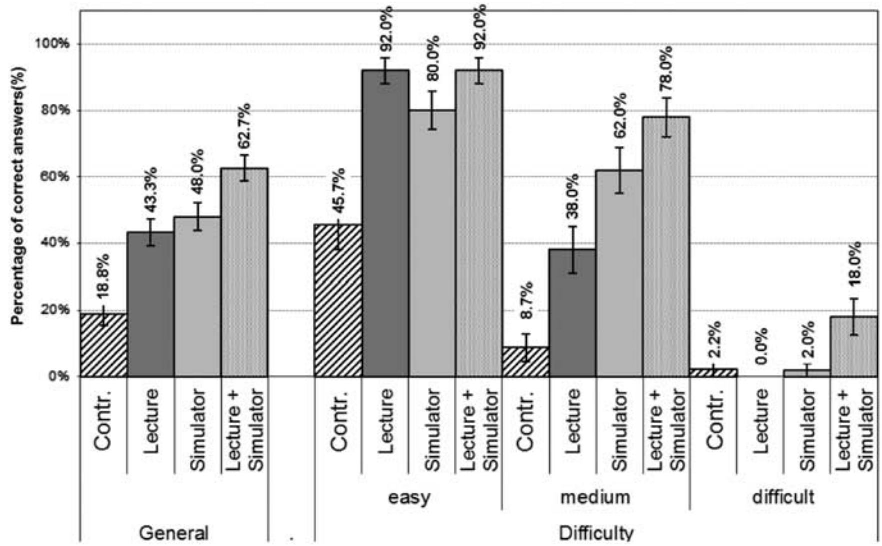

Figure 7 Percentage of correct answers according to the teaching resource used.

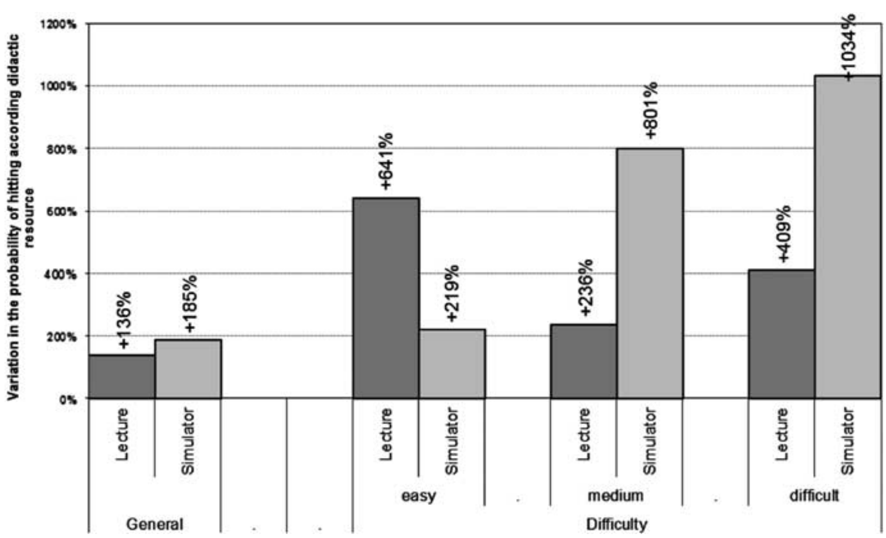

Figure 8 Variation of the probability of correct answers according to the teaching resource used.

The theoretical class (theor.) is the group where only this category of class was used as a resource. The simulator presents the group where only the simulator was used. The theoretical class and the simulator (theor.+simul.) represent the group that experienced both resources.

After analysing Figure 8, it can be seen that the percentages of correct answers in the easy questions were the same when the theoretical class and the theoretical class associated with the simulator were used (92%). In the medium questions, students who did only the class with the simulator answered the questions correctly about 62% while those who did only the theoretical class answered the questions correctly about 38%. The students who took the two classes responded to 78% of the questions correctly. As the level of difficulty of the questions increases, the influence of the simulator, in the amount of correct answers, increases. When the questions are easier, any level of knowledge is sufficient to answer these questions correctly. Now, when the questions become more difficult, the simulator makes the difference for the student to approach the actual execution of the physical phenomena.

In general, the use of the simulator influenced more in the number of correct answers than the theoretical class. The association of the two resources further increased the amount of correct answers.

Figure 8 shows that the use of the simulators provides a means for the improvement of 185% in probability of correct answers while the theoretical class, a means of only 136%.

To answer the easy questions, the theoretical class was enough. For medium questions, the increase of probability was of 801% when the student did the class with the simulator. For difficult questions, this value was even higher, about 1034%. Note, again, that, as the difficulty of the questions increases, deeper knowledge is needed.

According to Figures 7 and 8, the results derived from the statistical analysis show that simulators provide a gain for the improvement of students in classroom, reinforcing the teaching–learning element. The practice with the simulations significantly increased the chances of students giving correct answers to the evaluation questions.

When the use of simulators was associated with the theoretical class, the efficiency of this tool was even greater. This can be explained by the fact that resources complement each other. The theoretical class provides prior knowledge to the use of the simulator, and the simulator provides an approach, by means of practice, to the theoretical class.

5. CONCLUSIONS

The results showed that the simulation models, built with free versions of software and usually used for development of DES models, can also be utilized as a tool for teaching help. This is an opportunity that can be increasingly exploited, including in classes in high school. Both models used in a class of Telecommunication technical course, as in a Physics class, presented results that can be seen as positive.

Although not replacing the laboratory practice, the use of simulators may represent an interesting alternative in schools with few resources, since, unfortunately, this is still a reality found in many undeveloped countries. The construction of these models often requires only a computer with the free version of simulation software. Currently, many schools already have computer laboratories that are less expensive than laboratories with equipment for actual experimentation. These laboratories can be used in the construction and presentation of simulation models.

It is important to emphasize that the models were developed by the teacher of the subject after having conducted a training course. Thus, once the teacher himself is the modeller, he can make changes on the model, adapting it to the needs required to facilitate the illustration of concepts to be covered in classes. The fact that the teacher himself elaborates models can be presented as stimulus for preparing more dynamic and interactive lessons.

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