Design principles about the use of simulators to improve student engagement in physics teaching

Abstract. Incorporating new digital technologies into teaching is of fundamental importance in an interconnected world. In this sense, this work seeks to develop design principles on how to use simulators and recorded reports to improve student engagement and, consequently, learning. For this, we made a Design-Based Research (DBR) to identify the supports promoted by the use of simulators. The main findings are that simulators accelerate learning through discussions in investigative practices and promote a type of engagement where students seek to learn beyond traditional exams.

1. Introduction

Student engagement improves learning, better science performance, and long-term participation [1]. In addition to internal factors (student motivation), external factors must be observed, such as the learning environment. Especially when we remember the reports of low student engagement at the time of isolation imposed by the COVID-19 pandemic. It is in this context that it emerges, with classes coming out as part of an effort to address recurring problems by high school students, in the interior of Rio de Janeiro, during the restrictions imposed by the pandemic. According to students, they have difficulties to learn because they lack the motivation to study and interested in students.

Also considering that experimentation and discussions are important parts of science teaching, this work carried out a Design-Based Research (DBR), to build design principles on the use of simulators in teaching. The objectives were: to identify the supports brought by the simulators; the type of engagement that the practice promoted; and identify which were the main learnings reported by the students.

2. Theoretical-Methodological Framework

The choice of DBR is justified by the strong relationship between DBR and the use of digital technologies of information and communication (DTIC) in research in Education. According to McKenney and Reeves [2], DBR is committed to developing theoretical insights and practical solutions simultaneously, in real contexts, together with stakeholders. Many different types of solutions can be developed and studied through educational design research, including educational products, processes, programs or policies.

The phases of the process of development of interventions with the use of DTIC pointed out by Reeves [3] were used: phase 1 – analysis of the educational problem; phase 2 – development of the pedagogical artefact; phase 3 – intervention; and phase 4 – retrospective analysis to create design principles.

The identification of educational problems (phase-1 of the DBR) began when a high school senior class, composed of 22 students aged 16-19, was called to a meeting with the teachers so that the students could comment on their difficulties in remote teaching and to seek to solve problems with low grades and little engagement in classes.

According to the students, they were not able to deepen their knowledge about the topics studied and had difficulty concentrating on classes, as they thought that remote classes had an excess of slides and that this was very exhausting. Also, they complained that there was a lack of faster feedback on their performance in activities. Thereby, the challenge was to circumvent the problems presented by the students, seeking to promote more participatory and differentiated classes that would provide faster answers about their performance.

A technology-mediated investigative approach was chosen because some studies show that students learn more when they engage in interactive investigative activities [4]. It was also taken into account that some research [5, 6] highlights the importance of sociocultural aspects in learning. In this sense, Neto and Struchiner [7] also report that when students feel more voiced in the planning process of school activities, they also participate more in their own activities and this has the ability to improve the classroom environment. Therefore, it was believed that the use of simulators, with subsequent seminars given by the students on the topics studied, could offer some type of different environment that generates, at the same time, engagement through interest, immediate answers to their questions (simulators and tests hypotheses) and diversified learning (not only in terms of content but also procedural and attitudinal). With that, the phase of construction of the pedagogical artefact began (Phase-2 of the DBR).

As part of the activities, students needed to answer questions about the phenomenon studied, where the use of simulators served to provide students with the possibility to test their answers, in addition to making the class more interesting for everyone through active participation. To this end, the class was divided into groups of up to four students and different questions about the same phenomenon were given to the groups, for later reporting to the entire class. After discussing the results with the group members, the students also had to present their findings to the class in the form of a seminar. At the end of the activities, the students were interviewed to find out their perceptions about the activity, what they learned and what suggestions they would like to make to improve the activities.

It was chosen to use the software developed by the University of Colorado, in the United States of America, called PHET (Physics Education Technology). The choice is due to the fact that, in addition to being free, it has a large number of possibilities for changing variables and several experiments.

Regarding supporting theories to assess the type of engagement, we used the conceptualization developed by Fredricks, Blumenfeld and Paris [8], who propose three forms of engagement: (i) affective-emotional engagement, including attitudes, interest, sense of belonging and identification; (ii) cognitive engagement, including persistence, willingness, motivation and psychological investment to learn; and (iii) behavioural engagement including participation in activities.

The categories of Zabala [9] were also used, which suggests that the contents to be learned can be observed in three categories: attitudinal, conceptual and procedural. Conceptual contents refer to the active construction of intellectual capacities to operate symbols, images, ideas and representations that allow organizing realities. The procedural contents refer to having students develop instruments to analyse, by themselves, the results they obtain and the processes they put into action to achieve the proposed goals. At last, the attitudinal contents refer to the formation of attitudes and values in relation to the information received, aiming at the student's intervention in their reality [10].

Based on the class curriculum, topics of electromagnetism, radiation, thermal physics and modern physics were selected to carry out three tests of the educational prototype. To evaluate the learning of specific physics content, pre-test and post-test were carried out with the students. An orientation script was also provided for the recorded report, where students needed to show their research questions, their findings and discuss about the skills and competences they considered they had developed to carry out the activity.

3. Findings

The main findings reveal that there was faster and deeper learning of the content studied, where twenty students (90%) reported that they found it more fun and productive to learn using simulators, compared to lectures. They also commented that the discussions promote greater motivation and curiosity to study the themes.

According to the students, the fact that they could see theory in practice (application of theory in simulation) made them have a more profound view of the topic. In addition, sixteen students (70%) in the class also claimed that the theory made more sense when they saw how changing the values of the variables can impact the results. These statements show the importance of using simulators to create an application context for the theory. Similarly, Krajcik and Mun [11] comment that content-free science learning practices lack conceptual tools for students to use. Therefore, any situation leads students to develop isolated ideas, that is, experimental practices without knowledge of the concepts or pure concepts without their application visibility do not support problem-solving and future learning. Thus, the learning of concepts should not be isolated from environments that allow their application in practical situations. In this sense, the simulator was of great value.

Another interesting finding was that some students reported the need to carry out systematic and in-depth reviews of the topics because of the investigation questions. Many students claimed that the questions motivated them to study more than if they were simply taking a test. According to them, the test questions they are used to are very similar to the questions contained in the textbook. However, the activity (pedagogical artefact) presented questions that forced them to think and discuss. It is important to highlight that these statements are corroborated by the observations of the pre-test and post-test, where there was an increase in the rate of correct answers, from 11.9% to 77.8% when using the simulators.

Regarding procedural learning, students claimed that the part of recording videos was challenging because it had a time limit and the subjects were complex. Many reported the concern of talking about something to colleagues without them understanding what they wanted to say. This forced them to think of the right words they had to use so that their experience and report were well understood. Consequently, students had to learn to select content, summarise their findings and adapt the language to peers. According to Zabala and Arnau [12], activities that involve searching, analysing, organising and communicating ideas can be classified as procedural content. In this sense, the activity proved to be useful for developing communication skills and competencies and for the identification of central concepts. It is important to remember that the ability to express oneself orally with correction and clarity is essential for working life in any profession.

A large part of the class (70%) claimed that they had to record the same material several times because they thought it was not good. However, this helped to better select what was going in and what could be withdrawn. In addition, they claimed that recording several times helped to consolidate the learning and give more security to talk about the subject. These statements point to the need for repetition in the learning process.

It can be seen that, by placing themselves as protagonists in the construction of knowledge, they had to think about the listeners (adequacy of content and language) and the theme itself. This can give them a different dimension on what the teaching role is like and on how complex it is to select and adapt content. On the other hand, this ended up generating new relationships of interest because they claimed that they paid more attention to what their colleagues said than to the teacher. According to them, when a colleague had to present a topic, it was received as a different voice that deserved attention. This indicates the importance of observing how the relationships among them as a necessary part to develop learning environments. Ergo, giving voice to students was positive and allowed them to look at other aspects of a class and promote a different engagement.

The results point to changes in attitudes, interests, and sense of belonging when working in a group. In this way, the engagement was the affective-emotional one. In this sense, Fredricks, Blumenfeld and Paris [8] indicate that, if there are changes in learning environments, positive changes in the various facets of student engagement may also occur.

We also identified in the students' speech that the activity affected their will, motivation and psychological investment to learn, which is characteristic of cognitive engagement [8].

4. Design Principles

Below we present the principles, seeking to make explicit the main findings and the decisions taken throughout the process, indicating suggestions in which simulators are useful to face educational problems in similar contexts.

4.1. Principle-1: Simulators support the creation of a working environment on abstract and complex phenomena

It is noticed that the use of simulators helps in the learning of complex ideas that usually take a long time to learn, allowing students to interact with underlying models of scientific ideas and experience phenomena that would be very difficult without their support.

It was also verified that the use of simulators offers specific supports that can be seen as complementary to the physical laboratory and as differentiated strategies for students who live in places of difficult access, or who are subjected to some type of isolation, such as that imposed by the covid-19 pandemic.

4.2. Principle-2: Simulators have specific advantages over the physical laboratory

Taking into account the high cost of creating physical laboratories, as well as the cost of inputs to carry out the experiments, we indicate the simulators as important allies in this process for three reasons: 1) because the simulation preserves several components of the physical laboratory by the previous testing in the simulator; 2) because it allows all students to do the experiments individually and in groups. This solves the problem of the low amount of equipment compared to the number of students. In the physical laboratory, it is common to see many students using the same equipment or just looking at the teacher's exposure. This can limit learning; 3) The simulator also allows the student to redo the experiment as many times as necessary. In this way, the student assumes control of the experiment, and of the learning itself, without the risk of accidents or damage to himself or the laboratory.

4.3. Principle-3: Using the simulator supports reflection and discussion of ideas (cognitive support)

As seen, the fact that they could see the theory in practice (application of theory in simulation) made them have a more in-depth view of the topic. In addition, the students claimed that the theory made more sense when they saw how changing the values of the variables can impact the results. These statements show the importance of using simulators to create an application context for the theory. Concept learning should not be isolated from environments that allow its application in practical situations. Therefore, simulators served as cognitive tools because they facilitated students' reasoning and created a suitable environment for concepts to make sense [10, 13].

4.4. Principle-4: Using the simulator collaboratively favours affective-emotional engagement

The results indicate that there were changes in attitudes, interests, and sense of belonging when working in a group. The perception of belonging to the group promoted changes in the learning environment, generating positive changes in student engagement [8]. This is in line with Rogoff's [5, 14] claim that motivation for learning comes from participating in culturally valued cooperative practices. It can be argued that the use of simulators was re-signified by students as a space for building knowledge in the school environment and as a learning community, which affected students' willingness, motivation and psychological investment to learn.

4.5. A Principle-5: The use of simulators helps to develop procedural skills

Using the simulators provides more time for discussion among collaborators about the concepts, promoting learning about how to work in groups and negotiate ideas and meanings. Therefore, learning to listen to other's opinions and seeking to better base their speeches stimulate socialisation, which makes them learn more [5, 6]. For that reason, in the phase of elaboration of the activity reports, it was observed that the students developed competencies and communication skills. Mainly because they have to select content, learn to make good summaries and adapt the speeches to the audience that received their reports.

Another procedural highlight can be identified in the claim of most students about the need to delve deeper into the subject to feel more secure in the presentation. Thus, they developed the habit of going beyond the textbook, seeking to base their speeches on academic materials of levels above their own. This suggests that putting students in more complex activities, but which are well structured, makes students seek more knowledge rather than demotivating them.

4.6. Principle-6: The use of the simulator, associated with other strategies, supports the self-assessment of their own learning in a faster and more interesting way for the student

The results allow us to say that the use of the simulator promoted faster learning of central ideas about complex topics, such as the photoelectric effect, for example. As we have seen, core ideas and crosscutting concepts provide students with the conceptual tools to think about and explain phenomena. Thereby, when they needed to create hypotheses and test them in the simulator, students more quickly identified patterns of cause and effect and explanatory models about the phenomena. This also gives an idea of what a researcher's job is like, which is an additional gain.

Furthermore, the strategy of asking students to record their reports created the need for them to think about their own learning (metacognition), in addition to needing to develop ideas in formats that were easy for colleagues to share and to be correct at the same time. As a result, they have become media content creators, something that is well known by students and that brings the school closer to the daily reality of its students, who are so used to this type of language [15]. Mainly because it introduces playfulness, which creates a better learning environment [16].

5. Conclusion

Concluding, we can say that there was a stimulus for engagement through the use of simulators to test ideas and as a support to cognition and awareness of learning itself. We also believe that our research points to relevant suggestions for the use of simulators. Finally, we understand that all research has limitations that inspire recommendations for future studies. Hence, we suggest that new analyses be carried out in other contexts, moments and disciplines, to deepen the knowledge pointed out in the present study.

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