Implementation of an active instructional design for teaching the concepts of current, voltage and resistance

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Abstract. In the present work we show the implementation of a learning sequence based on an active learning methodology for teaching Physics, this proposal tends to promote a better learning in high school students with the use of a comic book and it combines the use of different low-cost experimental activities for teaching the electrical concepts of Current, Resistance and Voltage. We consider that this kind of strategy can be easily extrapolated to higher-education levels like Engineering-college/university level and other disciplines of Science. To evaluate this proposal, we used some conceptual questions from the Electric Circuits Concept Evaluation survey developed by Sokoloff and the results from this survey was analysed with the Normalized Conceptual Gain proposed by Hake and the Concentration Factor that was proposed by Bao and Redish, to identify the effectiveness of the methodology and the models that the students presented after and before the instruction, respectively. We found that this methodology was more effective than only the implementation of traditional lectures, we consider that these results cannot be generalized but gave us the opportunity to view many important approaches in Physics Education; finally, we will continue to apply the same experiment with more students, in the same and upper levels of education, to confirm and validate the effectiveness of this methodology proposal.

1. Introduction
The innovation and implementation of new educational practices require a constant reflection on the elements and actors involved in the learning process [1]; on the first hand, at least, three elements can be identified clearly, one element is all the group of learning activities and materials that students can use during their instruction to facilitate the comprehension and understanding, of a part or a whole concept or procedure in a specific topic boarded; a second element is the group of methodologies and learning sequences that can be implemented to our students and how these will impact in their learning process taking the use of the first element guided by a teacher, and finally a third element is the evaluation process which considers the measure of the progress during the learning process not only at the end of the instruction but during all the learning process. All these three elements in execution generate the learning process by itself, based on how the students are guided by a well-oriented methodology that includes materials and activities with its corresponding evaluation evidence.
Particularly, in hard-disciplines like Engineering and Science these elements require a wide variety of learning materials and activities because of the learning styles and motivations that are presented in the students, a well-oriented methodology is necessary because the topics in these disciplines are focused in a long-term learning in students; the concepts viewed can be impacted in their future academic and personal lives, the evaluation must be a tool that facilitate in the teacher the general view of their students and how all the learning process is taking place in the learning environment, independently that if the environment is in the classroom or virtual. On the other hand, the actors involved in the learning process are represented by the students, the teachers and researchers in education. We can consider also to the authorities and the family as another actor that participate in the learning process, but the most directly involved are the three actors mentioned firstly.

Currently, the curriculum in many Sciences and Engineering disciplines encourages the use of various types of learning and collaborative activities with the students in the classroom at different educational levels; these let the student to perform her/his learning process and promotes a more dynamic interaction between the teacher and the students. As a consequence, it facilitates the integration of the knowledge that students acquire, obtaining a better connection between the formal and concrete knowledge, facilitating the transfer of this to daily activities. We must take care with the design of the learning sequences that students have to perform, because they can be affected by a good or poor learning.

The comic has been employed in various ways in the learning process of different Physics' concepts [2]. One way can be seen as a motivational element, which allows to the students the introduction of a physical concept [3]. A second way is the use of the comic as an educational tool that serves as the bridge between the process of finding information and achieving a meaningful learning [4]. And finally, the comic can be seen as a goal by itself, to analyze and synthesize what has been learned by the student, that is, evaluate the process of creating and fostering teamwork. In France, Jean-Pierre Petit created a series of comics called "scientific comic" and founded the association "Knowledge without Frontiers", together with Gilles d'Agostini [5], with the aim of freely distribute their comics of science. These have been translated into 28 languages to divulge some fields of science, especially in physics and mathematics.

The aim of this work is to present the results from the design and implementation of a learning sequence that used a comic-based-on and different low-cost experiments for the learning of the electrical concepts of Current, Voltage and Resistance. The learning sequence was implemented to a group of 10 high-school students with ages between 15 and 18 years old, a control group was introduced to compare the results of this learning sequence proposal.

The organization of this paper is as follows. In section II we present the description of the learning sequence designed and implemented to the students also the evaluation instrument that was used to measure the effectiveness of the learning sequence is described. In section III, we present the results generated by the implementation of the learning sequence and some discussion are presented to identify important results in this experiment. Finally, in section IV the conclusions are presented analyzing the general results and future work to do for this kind of experiments in the learning fields of Physics, Science and Engineering.
2. Research Methodology Description
Orlaineta, et. al. [7], have designed and implemented a learning sequence based on Active Learning as a general methodology, which considers that students must work on a hands-on minds-on environment. Their learning sequence encourages the students to get involved in their learning process and promotes a long-term learning by the activities that the students have to do. Partial results of this proposal have already been reported briefly in [5], but in this contribution we present a complete analysis by ensuring a stronger conclusion.

2.1. Design of the Learning Sequence
Garcia and Sanchez [2] have proposed the design of learning sequences having in mind that the students are the principal and final actor during the learning process, they consider that the students must be guided from a concrete point of view of the world to a formal point of view in the discipline. A six-steps instructional design is proposed to achieve this goal and these are defined with some flexibility to the teachers for the designing of more focused learning sequences. A brief description of the learning sequence is presented.

- TO START. A very concrete question must be proposed, it is strongly recommended to formulate an everyday life question that can promote the introduction of the concept and disrupt the students’ minds. For this experiment the question was: Why does not turn on the light bulb?

- TO PREDICT, OBSERVE AND THINK. First the students must make some predictions for answering the question and write down on a piece of paper. After, low-cost experiments must be performed by students in small teams (groups of three students are recommended). These experiments must be performed by the groups and each student can observe carefully the phenomena and think individually about it. For this experiment we implemented the next low-cost experiments: Communicating Vessels for the potential difference concept, a lemon as a battery and tickle in the tongue for the electric current concept and communicating vessels and the filament of a light bulb for the electric current concept with other intention different than the potential difference.

- INTRODUCING NEW IDEAS. The same small groups perform a discussion about their beliefs and thoughts of the low-cost experiments observed, generating a brainstorming in the groups. After they do an individual reading of the comic [9], which can be downloaded for free from [6] they have to draw a mental map of the concepts that were identified. Finally, they share their mental maps and discuss about their ideas. At the end the teacher gives a brief explanation about the concepts observed in the experiments.

- TO APPLY. Students have to perform experimental activities related to the function of an electric circuit; they have to measure resistance, current and voltage. The observation of how the brightness in a bulb changes when the voltage varies, must be identified by the students. As evidence of this activity students have to share their ideas with their peers and discuss in small teams.

- TO SYNTHESIZE. Learning must be more specific with the topics covered, in this stage, students must identify the behavior of an electric circuit and also the serial and parallel configuration of resistance must be clearly identified.

- TO EVALUATE. Students must conclude the comic, this is an important stage, because the comic that was used during the instruction was blanked in some dialogues with the intention
that the students filled them out with the correct concepts, developing the creativity in them to write down their conclusions and ideas about the physical phenomena.

2.2. Evaluation of the Learning Sequence

To evaluate the learning sequence applied to students; two evaluation instruments were designed, the first one used was a multiple-choice test, composed of thirteen items, it was used as a pre-test and as post-test to evaluate the previous ideas of the students and the final ideas of them after the implementation of the learning sequence, respectively; these items were disciplinary and conformed from the Electric Circuits Concept Evaluation (ECCE) developed by Sokoloff [11], only ten items were selected because they cover the concepts boarded in the learning sequence. And the other three items were selected from the proposal of Periago and Bohigas [12] to analyze preconceptions in the students.

To evaluate the students' perceptions and attitudes related to the learning sequence a semantic differential [13] was applied. This instrument, let us to identify in a semi-qualitative way how students felt with the implementations of the learning sequence, it uses a qualitative scale like "funny, difficult, useful, important, time saving, pleasant and their corresponding antonyms", and after we change it with a discrete scale based on numbers.
2.3. Methodology implementation and study population description

The learning sequence was implemented in the ‘Instituto de Educacion Media Superior, IEMS’ of Mexico City, this institute works with a free syllabus scheme and based on a competency learning model. The subject where the learning sequence was implemented was Physics II (Mechanics and Electromagnetism). In this research work, two groups are defined, a group ‘A’ with 9 students as the control group and a ‘B’ group with 10 students as the experimental group; both groups were conformed with students between 15 and 17 years old. Two teachers were involved in this sequence, one worked with the control groups and the other one with the experimental group.

The methodology implemented with the group ‘B’ was previously defined in the section 2.1, here we would like to add that it was divided into 8 sessions of 90 minutes-duration each session. In the first session the teacher explained how they will work during all the learning sequence, and the pre-test was applied with a duration of 45 minutes. From session 2 to session 8 the learning sequence was implemented. Finally, two weeks later, the post-test and the semantic differential was applied to students.

For the group ‘A’, the methodology implemented was conformed also into 8 sessions of 90 minutes-duration each session. In session 1, the teacher explained to the students how the work was going to be conducted during the rest of the sessions and the pre-test was applied to students with a duration of 45 minutes. A lecture-way session was implemented during the rest of the sessions, where the teacher only presented the topics in an expositive way, two lab sessions were guided by the teacher where students have to follow instructions and perform activities, with little reasoning related to the activities and results, the students have to fill out some schemes, measure some values of resistances, current and voltage and to identify the colours-code in a physical resistance also the serial and parallel circuits’ arrangement was seen by the students. The students during their instruction used an exercise book that contained a set of questions and problems related to the topics. Finally, two weeks later, the post-test and the semantic differential were implemented.

3. Results and discussion

Once that we collected the data from the assessment instruments: pre-test, post-test, semantic differential and student evaluation work (continuation of the comic), we proceeded to analyse them.

For the Conceptual Normalized Gain (CNG), we observed that the group ‘B’ obtained a 0.43 value (which is considered as a medium gain); for the group ‘A’ a 0.20 CNG was observed (which is situated as a low gain), with these results we can observe that the learning sequence implemented in group ‘B’ presented a better performance respect to group ‘A’. We would like to mention that a better improvement like, electrical current flowing through a point in a single circuit, the equivalent point of a parallel circuit, the brightness of a light bulb connected to a simple and parallel circuit, and the way that the electric current flows from a battery and passes through a light bulb, were presented in the students.

To analyze the learning in the students, based on the answers from the test, we applied the Concentration Factor (CF) proposed by Bao and Redish [14].
Figure 1 shows the CF for the experimental group while in figure 2 shows CF for the control group, in both figures, ● symbol represents the result of the pre-test while ◊ represents the result of the post-test.

In the control group that did the pre-test we found that 90% of the students presented, a low-gain region where the concepts are distributed as follows: 30% of students had random conceptual models, another 30% had at least two different misconceptions models and finally another 30% presented a one-wrong conceptual model, the rest of the 10% presented a middle-gain region. In the case of the experimental group that did the pre-test we found that 100% are in a low-gain region, they were distributed as follows: 46% of students had random conceptual models, another 46% presented two predominant erroneous conceptual models and the rest 8% presented a single wrong conceptual model.

In the control group that did the post-test we found that 46% stayed in the same low-gain region, the distribution of these students is as follows: 8% of them kept random conceptual models, 15% kept two different misconceptions models and finally the 23% presented a one-wrong concept model. For the rest of the group, 38% moved toward a middle-gain conceptual region and finally the 16% of the class presented a high-level region of understanding. In the case of the experimental group that did the post-test we found that 24% kept in the low-gain region, the distribution of these students is as follows: 8% kept a random conceptual model, another 8% presented a two misconceptions model and the last 8% kept one-wrong conceptual model. It is important to notice that 53% of the student obtained a middle-gain conceptual region which can show us the effectiveness of the learning sequence and a 23% of students demonstrated a high-level region of conceptual understanding, which is higher than the presented by the control group.

The semantic differential showed us important aspects of how students perceived from the learning sequence. In general, they commented that the using of comics and low-cost experiments promoted in them a self-confidence and understanding of the topics viewed. Also the students confirmed that the use of these learning resources were funny and enjoyable, respect to other courses where the teacher
only explains the topics and they have to solve some basic exercises. The time consuming and the difficulty in the activities performed were not a negative issue in this learning sequence.

While the learning sequence was performed, we could observe that students could construct more clear and oriented short ideas of the dialogues that they read previously. In addition, the students decided to use the same vignettes taken from the comic because they didn't feel comfortable with the creation of new ones. Once we obtained the completion of the comics, we could observe that students could retain the concepts viewed in the low-cost experiments and used them to explain and conclude the comic using a good understanding of the concepts with an appropriate science language and presentation of the physical concepts.

4. Conclusions

In this study, we can see that the use of an active learning methodology and a learning sequence well designed for students can achieve a good comprehension of different physical concepts, like the electrical circuits' concepts, as in this particular case. Following the ideas proposed by García and Sánchez [2], we could see that with a well-defined learning sequence, students can learn and understand different learning topics with a well-oriented scheme. The design and implementation of the activities promoted in the students a better comprehension of physical concepts and self-confidence, achievement in students for more motivation in the learning process for some topics considered in many cases difficult to learn and to understand was obtained.

Comparing both groups were useful, and we believe that it is necessary when we try to implement new approaches and ideas to promote a long-term learning, but also we should to have in mind that the learning must be promoted in the control groups, considering for future works the use and comparison of different active learning methodologies, focusing on the understanding of best practices for learning and we must leave away the idea of a control group, based on a traditional way of teaching.

We think that it is clear and necessary to implement more active learning methodologies and try to combine them for a better improvement in the learning process with students, and in the learning of topics like Physics and Engineering is more important for countries in development like Mexico and more Latin-American countries.

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