Using experimental modules to favour meaningful learning in high school physics

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Abstract. In this study we propose the use of experimental modules in order to favour meaningful learning. The modules are short experimental activities employing everyday materials. The study was done at UNAM’s CCH-Oriente in Mexico City during a Physics IV class from February 28 to April 4, 2018. The learning was measured using a diagnostic assessment and two evaluation assessments. The written work of the modules was measured with a rubric. It was found that the use of the experimental modules indeed favour meaningful learning by the students, as the scores in the evaluation assessments were above the diagnostic and did not return to a base state 3 weeks after instruction. We verified that students were not answering the assessments randomly with a paired T-test, all except one of the pairs were below the 0.05 statistical significance. We sought a correlation between the written work in the modules and the answers in the assessments with a chi squared test but found none.

1. Context
In a previous research [1] conducted at the Faculty of Sciences of the Universidad Nacional Autónoma de México with a group of Biology freshmen we found that the students still have naïve ideas regarding electromagnetism. These ideas range from small misconceptions to fully established ideas that are, in the end, nurtured by the teachers. Moreover, students dislike Physics all together due to the way it is taught in middle and high school. The preferred teaching method for high school physics is lecturing, which results in a lack of scientific attitudes, interest and motivation by the students.

In order to know if this was just an isolated case or a more general issue, we sought the OECD’s (Organization for the Economic Cooperation and Development) PISA (Programme for International Student Assessment) results. The PISA measures the performance of students around age 15 and one of its areas is scientific competence. This area includes scientific knowledge and the use of said knowledge to identify questions, acquire new knowledge, explain scientific phenomena and draw conclusions based on related scientific evidence [2]. The results of PISA 2015 place Mexico far below the OECD’s mean and slightly above Latin America’s in scientific competence. Mexico’s score was $416 \pm 2.1$, OECD’s mean $493 \pm 0.4$ and Latin America’s $408 \pm 0.8$ [3]. This reinforced our notion that there is a deeper issue at hand regarding high school physics teaching.

2. Proposal
With this in mind, we asked ourselves if and how this situation could be changed. More specifically, if a change in the way teaching high school physics could impact the learning experience of the students in order to improve the conceptual knowledge of the students. Knowing that teachers are reluctant to change their teaching styles, we proposed the use of experimental modules as an aid for the teaching-learning experience. This study has two objectives: the primary one: if the usage of such modules favours meaningful learning and a secondary one: to verify if there is a correlation between the quality of the written work done in the modules by the students and their learning.

2.1 Experimental Modules
The experimental modules proposed are short, maximum 30-minute-long, experimental activities with everyday materials. The simplicity and the use of everyday materials promote students’ thinking, favour contextualized learning, and concept comprehension [4-6]. The proposed modules are based on the POE (Predicting, Observing, Explaining) method by White and Gunstone [7].

The modules consist of two main parts: a worksheet and the experimental activity. The worksheet is where the student can find the name of the module, instructions, guide questions, and the steps for the experimental activity. In it the students must write down their hypothesis or predictions on the activity, their observations, and finally their conclusions. The written hypothesis is a fundamental part of the module, as found by Miller et al. [8], if the hypothesis is written down, the student is more prone to understand the concepts underlying the experimental activity. The experimental activity is chosen or designed according to the conceptual objective the teacher is aiming for. If there are too many concepts involved in a single experimental activity, the students may get lost and the module loses its purpose.

The steps in implementing the experimental modules are as follows: first, a brief explanation of the instructions to the students. Next, the students must write down their personal hypothesis of what they think will happen in the experimental activity. After all the students have written down their hypothesis, they proceed onto the experimental activity. At last, the students register their observations and finally they compare and contrast them to their hypothesis to draw a conclusion. During this last phase the teacher may pinpoint certain details in order to reach the objective of the module.

2.2 Methodology
The research schematic for the study is shown in figure 1. The labels are: G, groups used in the study; M, a diagnostic and two evaluation assessments; and X, the classes where the modules were implemented. The research was done in two groups of Physics IV at the UNAM’s CCH Oriente high school. Physics IV is part of the last semester of high school and consists of two weekly 2 hour classes. Both groups had the same teacher and differed in one being a morning class and the other an evening class. The students’ ages range from 16 to 18 years old. The whole research spanned from February 28 to April 4 2018, which includes the interventions made and both of the evaluation assessments. The three assessments consisted of multiple-choice questions selected from Maloney 1985 [8] and Maloney et al. 2001 [9], and no changes were made to them. An example of the assessment can be found in the appendix. The diagnostic assessment was applied on February 28 prior to the intervention, the first evaluation assessment was applied on March 21 and the second one on April 4. The time gap between the end of the four classes was to ensure we were measuring learning and not memorization. We expected a descent in grades from the first to the second evaluation.

![Figure 1. Research schematic.](image-url)
The modules were implemented at the beginning of the class with one exception. The class topic during the study was magnetism and electromagnetism, so the modules and interventions were planned with such objectives in mind. Five modules were prepared for the interventions: a magnetic train, an electrostatic pendulum, Ørsted’s experiment, a Lorentz’s force demonstration, and Faraday’s induction. The electrostatic pendulum was the only module implemented at the end of the session. Each of the modules had a specific objective: the magnetic train was an icebreaker, the electrostatic pendulum aimed at showing the lack of interaction between charges and poles at rest, Ørsted’s experiment proved the relationship between currents and magnetic fields, Lorentz’s force demonstration showed the interaction between currents and magnetic fields, and finally Faraday’s induction experiment demonstrated the relationship between moving fields and currents. The first class included the first two modules and subsequent classes only one. Figure 2 shows images of the experimental modules.

The first module was a magnetic train which consisted of a tongue depressor pasted on a cardboard with a series of soft magnets on each side. Beside the magnets two tongue depressors were pasted on their side in order to make a type of railing. With the “rails” finished students had to build the train, which was ¼ of a flat stick pasted on a cardboard and 1 magnet on each side. The central tongue depressor is used only to ensure the magnets are equidistant on the rails and the train. The next module was the electrostatic pendulum. In this module a polystyrene ball was covered with tin foil and hung from a string. The students charged the ball with a balloon, waited until it stopped moving and placed a magnet near it. The third module was Ørsted’s experiment in which the students placed a cable under a compass and touched both ends of a battery. The fourth module was the demonstration of Lorentz’s force. The lack of several power generators in the classroom and the high current used were the reasons why it was a demonstration and not a module done by the students. A doughnut was placed under a deep glass bowl filled with salty water and coriander seeds. A current was passed in the water between the centre and rim of the bowl with the power generator. The last module demonstrated Faraday’s induction. To help students understand the concept a thin copper wire was rolled on the outer edge of a plastic syringe and a neodymium magnet was placed inside the syringe.

3. Results

As can be seen from the image, the scores increased in a significant manner between the diagnostic and the first evaluation, and slightly between both evaluations. The second increment in the scores was unexpected because the dates were several weeks apart from each other and from the last class imparted. In order to know if the modules impacted the learning of the students more than a lecture class the normalized gain of averages [10] was taken into account, and the values are found in table 1. The gains of group 1 are in accordance with the gains found for interactive engagement activities in Hake 1998, in contrast to the gains of group 2. The gain between the diagnostic and the first evaluation for the totality of students is inconclusive but the gain between the diagnostic and the second evaluation falls in the values for an interactive engagement activity.
Table 1. Normalized gains of averages.

|               | Gain 1 | Gain 2 |
|---------------|--------|--------|
| Group 1       | 0.569  | 0.604  |
| Group 2       | 0.140  | 0.293  |
| Total Students| 0.372  | 0.462  |

To rule out a randomly answered assessment by the students a paired T-test was performed between the diagnostic assessment and each of evaluations. The values for t and p for each test can be found in table 2. As can be noted from the values of all the tests, except one, the p’s are below the threshold of 0.05 for statistical significance. With these results we can state that the students did not answer the different assessments in a random manner.

Table 2. T-test values and probabilities.

|                        | Diagnostic – Evaluation 1 | Diagnostic – Evaluation 2 |
|------------------------|---------------------------|---------------------------|
|                        | t            | p              | t            | p              |
| Group 1                | 5.651        | 6.997 × 10^{-6} | 6.513        | 8.032 × 10^{-7} |
| Group 2                | 1.446        | 0.162          | 3.308        | 0.003          |
| Total Students         | 4.840        | 1.335 × 10^{-5} | 6.725        | 1.767 × 10^{-8} |

The last test performed to the data obtained from the modules worksheet and the assessment scores was a chi squared test. With this test we expected to find a correlation between the written work of the module and the change in the answers of the questions the module was aiming for. As was stated before, module 1 was used as an icebreaker so it was not taken into account for this analysis. The target questions of the different modules go as follows: module 2 to item 2, module 3 to item 3iii, module 4 to item 4, and module 5 to item 5. The modules written work was ranked with a rubric that contained 5 traits and 4 dimensions ranked from 0 to 3, 0 being null work for such trait and 3 being a very complete mark. A set of 4 labels were created for the change in the answers: where the answer
was correct in both assessments, where the answer was wrong, where the answer was changed from wrong to correct, and where the answer was changed from correct to wrong. These labels and the total scoring in the module were used for the chi squared test for each module question pair and between the diagnostic and both evaluation assessments. The chi squared and its associated p values are shown in table 3. It can be noted that all p values are above the 0.05 threshold for statistical significance, which means that there is no correlation between the written work done in the modules and the change in answers between diagnostic and evaluation assessments.

Table 3. Chi squared values and probabilities.

| Group 1 | Diagnostic – Evaluation 1 | Diagnostic – Evaluation 2 |
|---------|---------------------------|---------------------------|
| Module 2 | 1.787 | 2.141 |
| Module 3 | 0.810 | 0.465 |
| Module 4 | 10.231 | 13.770 |
| Module 5 | 14.663 | 8.372 |

| Group 2 | Diagnostic – Evaluation 1 | Diagnostic – Evaluation 2 |
|---------|---------------------------|---------------------------|
| Module 2 | 1.501 | 2.274 |
| Module 3 | 3.965 | 0.960 |
| Module 4 | 4.686 | 12.800 |
| Module 5 | 11.790 | 14.694 |

| Total Students | Diagnostic – Evaluation 1 | Diagnostic – Evaluation 2 |
|---------------|---------------------------|---------------------------|
| Module 2 | 0.652 | 2.201 |
| Module 3 | 0.218 | 0.080 |
| Module 4 | 5.280 | 8.644 |
| Module 5 | 8.504 | 7.450 |

4. Conclusions and Implications
In conclusion, the use of experimental modules does favour learning in the students as can be seen in assessment’s scores. The permanence of the concepts after a 3-week period and the increase of scores in the second evaluation assessment proves that modules do favour meaningful learning and enhance the teaching-learning experience in the classroom. It was noticed during the study that modules themselves aid to increase the quality of the knowledge learned by the students but must be used in conjunction with other techniques to maximize students’ learning. Something worth mentioning is that the lack of correlation between the written work and the change in the answers was caused by the study’s set up. It is yet to be seen if the students’ post instruction conclusion on the modules hypothesis is correlated with the change in the evaluation’s answers. In summary, the use of experimental modules works as an aid for the teacher in order to improve the teaching-learning experience of the class while favouring meaningful learning of the key concepts of the topic.

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Appendix
This is the assessment used to measure the students’ learning.

Nombre: ____________________________

Instrucciones: Este es un examen de evaluación el cual sirve para conocer lo que aprendiste acerca del tema. El resultado no afectará de manera alguna a tu evaluación. No hay respuestas correctas ni erróneas, elige la que creas correcta para cada una de las preguntas.

1.- Un imán de borra golpea contra el suelo y se parte exactamente por la mitad. Elige la opción que creas explica lo que ocurre con los pedazos.
   a) Se parte en 2 imanes con la mitad de la intensidad del campo magnético del original.
   b) Se parte en un imán norte y un imán sur con la misma intensidad del campo magnético del original.
   c) Se parte en 2 imanes con la misma intensidad del campo magnético del original.
   d) Se parte en un imán norte y un imán sur con la mitad de la intensidad del campo magnético del original.

2.- Las siguientes imágenes muestran una partícula cargada en reposo frente a un imán. La magnitud y el signo se muestra dentro del círculo que representa la carga. ¿Cuál de las opciones muestra el ordenamiento del más atractivo al más repulsivo?

   1. \[ \begin{array}{c}
   \text{N} \\
   +1
   \end{array} \]  
   2. \[ \begin{array}{c}
   \text{S} \\
   +2
   \end{array} \]  
   3. \[ \begin{array}{c}
   \text{N} \\
   -3
   \end{array} \]  
   4. \[ \begin{array}{c}
   \text{S} \\
   -5
   \end{array} \]

   a) 3, 2, 1, 4  
   b) 2, 1, 3, 4  
   c) 1, 3, 2, 4  
   d) Todas tienen la misma fuerza.

3.- i) En la figura inferior dibuja como crees que es o se ve el campo magnético.
   
   ii) ¿Crees que el campo salga del plano del papel?
   
   III) Una partícula cargada se mueve a través del campo magnético generado por unos imanes, como se muestra en la figura. Elige la respuesta que creas explica lo que le ocurre a la partícula.

   a) La partícula se mueve hacia alguno de los imanes (arriba o abajo).
   b) La partícula no modifica su camino.
   c) La partícula se frena y se regresa.
   d) La partícula se mueve en otra dirección (dentro o fuera del papel).

4.- La figura de la derecha muestra un corte de un alambre el cual es perpendicular a la hoja. El alambre tiene una corriente I que sale del papel. ¿Cómo es la forma del campo magnético?

   a) Gira en dirección de las manecillas del reloj. 
   b) Gira contra las manecillas del reloj.
   c) Sale desde el centro en todas direcciones.
   d) No hay campo magnético.

5.- Las siguientes figuras muestran un imán cilíndrico y un foco conectado a un aro de cobre. El plano del alambre es perpendicular al eje de referencia. El movimiento de alguno de los elementos se indica con una flecha en el diagrama, ya sea traslación o rotación. Elige la opción donde el foco enciende más intensamente.

   a) I, II, III
   b) I, III
   c) III
   d) I
   e) Ninguno enciende
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