Testing A Teaching Intervention Strategy On Particle Physics For High School Students

Resumen:
In this study we propose a teaching intervention strategy based on modeeling with embodiment to cover updated concepts of matter components and their interactions. Students increase their interest towards modern physics and improve their results about contents after the intervention. Statistical differences between pre-test and post-test are found to be positively significant.

Keywords: Science education, embodiment, particle physics

1. Objective

This study shows the first results of a teaching intervention strategy that covers topics related with modern particle physics through Physics and Chemistry (P&Ch) subject curriculum at High School. This strategy is based on socio-constructivist ideas of modelling and has as its major novelty the use of embodiment. With *embodiment*, students are the active agents of the model, which wires some sensor-motor neurons improving a significant learning (Johnson-Glenberg et al., 2012).

In these first results we compare both pre-tests and post-tests in the second-to-last year of High School by using a sample of students from Valencia (Spain).

2. Theoretical Framework:

Most part of the P&Ch Spanish curriculum at the different High School levels is covered by topics related to the components of matter and their interactions. This is usually done (Tuzón & Sobes, 2014) by giving the students an out of date version of the model: the atom is a proton-neutron-electron system made by the electrical force. 20th century went much further on this conception building the Standard Model of Particle Physics, which considers also two nuclear forces and new particles to understand matter behaviour. Students do know something about this but show lacks in comprehension and learning structure (Tuzón, 2014), which motivates the proposal of a teaching intervention strategy. This need of an intervention is also supported by other studies in science education (Moreira & Ostermann, 2000; Tuzón, 2014): first arguing the bias introduced in the process of modelling if the version of the atom is unjustifiably stopped at the end of the 19th century ideas. And second, warning about the fact that missing updated ideas disconnects students from society today —which at the same time move students away from science subjects (Rocard et al., 2007)—. The impact that new physics has had on our lives (new technology, medical therapies, computing, new materials…) should be definitely treated in science class (Sinarcas & Solbes, 2013).

Modelling is a key process in science activity, and then it is so in science learning, as socio-constructivist studies suggest (Acher, Arcà, & Sanmartí, 2007). Modelling techniques are diverse, from working with objects and drawing pictograms to the use of mathematical formulas, there is a wide set of resources. In this research we use a particular way of modelling based on embodiment (Johnson-Glenberg et al., 2012). Embodiment means that students act as agents of the model; they are invited to play model roles in short sketches, resembling the physical process that is under study. This is demonstrated to activate some sensor-motor neurons that improve the learning process.

3. Methodology:

The teaching intervention strategy was driven by a researcher (the first author of this study) in a sample of 42 students of a High School center located in Valencia metro (Spain) The students were from the second-to-last year in High School with P&Ch elective. The intervention was pre and post evaluated with the same test consisted by 17 opened questions. The whole intervention took three sessions of one hour each, plus 40 minutes before and after them for the pre- and post-test respectively.

The test was the same as the one used to diagnose the level of knowledge of students regarding this topic (Tuzón, 2014), the questions covered basically four blocks: Block 1 of questions —forces and components of matter— assessed the knowledge according to what is specified in the curricula (typically classical models). Block 2 of questions —classical models limitations, new particles— evaluated the concepts that, although going beyond the classical models, can be introduced through the Curriculum (indirectly this is also a way to evaluate the use of modelling in science class). Block 3 of questions —Higgs boson, neutrinos, antimatter, LHC— assessed what students know about particle physics from extra academic sources (TV, Internet, literature, films). Finally, Block 4 of questions — colliders, CERN, current research— assessed the interest of students towards particle physics and its applications.
The answers to each question were evaluated in a scale of 0, 1 and 2, where 0 means the level of knowledge is low, below to what students are supposed to know according to curricula requests. 1 means the level is medium; student's concepts adjust to the classical models but do not show any knowledge about modern particle physics. And finally, 2 means the level is high; student's concepts show correct knowledge about updated concepts of matter.

The teaching intervention strategy was divided in three parts (see Table 1). Part 1 starts familiarizing students with the concepts they probably know. Activity A3) triggers the discussion towards the need of new ingredients to understand the atom. This part ends by completing the classical view (electron-proton-neutron plus electrical force) with a new interaction (the strong force) and new particles (quarks) as components of the nucleons. Part 2 introduces new particles (neutrinos) and the weak interaction; also treats forces behaviour as interacting particles, antimatter and, finally, explains the Higgs boson. Science-technology-society (STS) questions of Part 3 are covered at the same time.

Part 1 What do we know from what we know?	A1) Embody same-charged (electrons, protons) and uncharged particles interactions
	A2) Embody an atom taking into account previous activity
	A3) How is it possible that two same-charged particles (protons) are so close in the atomic nucleus? (Models for that)
	A4) Watch the descriptive video about cosmic ray detections at the beginning of 20th century and discuss how the new 'zoo' of particles can be explained
	A5) Knowing about new particles forming the proton and neutron (quarks), guess how they should interact to solve A3)
Part 2 More new particles	A1) Read Pauli's letter to the conference assistances from 1930's and discuss about this new particle he suggested. Is it the neutron we know today? Why?
	A2) List the fundamental interactions you know up to now, their strengths and ranges. Embody the behaviour of fundamental particles in the presence of one force or another.
	A3) Imagine these two ways of bringing a metal bucket that is three meters from you: (a) using a rope for pulling and (b) using a big magnet. What is the difference? How (or where) is the force being carried in the second case?
	A4) Embody particle interchange to explain repulsion. Play with the different interactions from A) and explain with this model their ranges in terms of the intermediate particles
	A5) Watch electron-positron annihilation photo
	A6) Embody matter-antimatter particles interacting in the class and discuss the "danger"
	A7) Embody same amount of matter-antimatter Universe at the Big-Bang and then assume an asymmetry (more matter than antimatter); discuss the results, what Universe do we have today?
	A8) Think of a famous person and embody the reaction of people when she/he enters a place. Embody now the same situation with someone unknown. Comment differences and listen about the Higgs role.
Part 3 Socio-particles (cross-wise recommended)	A1) Look on the Internet information about *CERN* and LHC details (length, temperature inside, vacuum, data recorded…)
	A2) Read about LHC 'dangers' that were reported some years ago, what do you think about them knowing the role of the cosmic rays?
	A3) Search for particle physics applications to our society

Table 1: Activities of the teaching intervention strategy. Italics indicate future suggestions that are not part of the current analysis.

Students worked in small groups to have their discussions before sharing them in front of the whole class. The teacher (researcher) was guiding the different guesses and encouraging students to participate, facing them to the contradictions and highlighting the main conclusions.

4. Discussion of Data

Figure 1 summarizes students' results from pre-test and post-test. Blue and orange points are total scores (normalized to 1) for the answers of each question of the pre- and post-test respectively. Bars represent the difference between post-test and pre-test. As can be seen from them, all differences are positive but one (question 1c) and most of them are positively high, meaning that the teaching intervention strategy was successful. Post-test results (orange points) are much better than pre-test's (blue points). As can be seen in the Figure, post-test's are in general over 0.5, meaning that the level of knowledge of the sample adjusts to a medium-high value, while the pre-test's results are lower.

Higher differences are observed in Groups 2 and 3 of questions, the ones covering new particle physics concepts, in both cases the improvements are notable, so the main goal of the intervention has been achieved. There are two exceptions, which are answers to questions 2b and 3f that do not change at all. 2b asks about the force that keeps the electron bounded to the nucleus, which is the electromagnetic force. Although there is no quantitative difference between the pre- and the post-test, the answers are qualitatively different: pre-test answers show confusion between what is a force and what is a feature. For example, we found many answers saying "the attraction force" or "the circular force". We found also many others saying "gravity". However, post-test answers to this question mostly mention "the nuclear force" or "the strong force", showing confusion between nuclear forces and nucleus-electron force. We think this should be fixed for a complete extension of this investigation. Almost the whole intervention tries to introduce two new forces (strong and weak) and particles, and this result shows that the electromagnetic force has been displaced. It is important to take time to summarize all new concepts and put them together with old ones. That is why we suggest to include A2 in Part 2 (italics indicates new suggestions) for next proves of this intervention. Question 3f asks about the CERN, although results from pre-test were not negative, there is no improvement. We think this is due to an excess of talking about the LHC rather than the CERN. Actually, there is no activity in Table 1 directly directed to CERN. Again, we propose an activity (italics on A1) of Part 3) to cover this. Results of questions 2a, 2c and 3c are particularly satisfactory. 2c asks about new particles that have been discovered; results were mid-level adjusted on the pre-test and improve significantly on the post-test. 2a and 3c got bad results on the pre-test and, also, significantly improve on the post-test. Question 3c was about antimatter and question 2a was the one about explaining how same-charged particles (protons) in the nucleus can be so close. Results are satisfactory compared to their previous knowledge.

Answers to Group 1 of questions get better results on the post-test but changes are more discreet. Some of these results were already not bad on the pre-test and the intervention improves them. The same happens with answers of Group 4 of questions; results were already high so the improvements are not so dramatic, showing that interest of students towards new physics was high and results higher after covering the concepts.

Embodiment appears cross-wise in the activities, but it is particularly related with questions of Groups 2 and 3 of the test, that are the ones getting a major improvement.

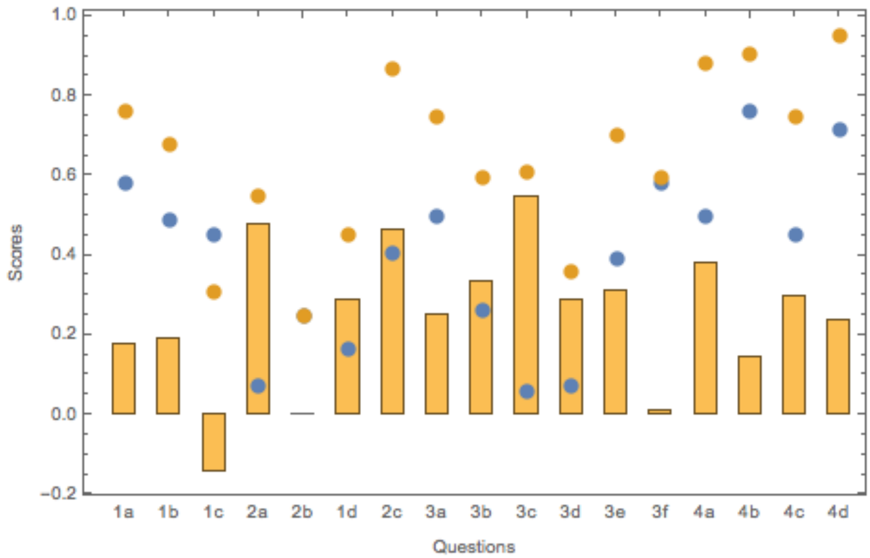

Figure 1: Scores of answers to Block 1 (1a, 1b, 1c, 1d), Block 2 (2a, 2b, 2c), Block 3 (3a, 3b, 3c, 3d, 3e, 3f) and Block 4 (4a, 4b, 4c, 4d) of questions, normalized to 1. Blue and orange points are pre-and post-test scores respectively. Bars show the difference between post-test and pre-test scores.

We also treated both pre- and post-tests differences statistically. Total scores differences were analysed using a Wilcoxon signed rank test. The result was statistically significant (one side p-value<0.001).

5. Conclusions

Including updated concepts from modern physics in science class is educationally recommended, first as a connection with society today, and second as part of the modelling process in science learning. In this study, we performed an analysis of a teaching intervention strategy that is used for the first time with a sample of 42 students from the same High school center located in Valencia metro. This intervention covers questions related to matter components and interactions according to the most recent theory in particle physics: the Standard Model. The intervention combines modelling with embodiment, where students act as the agents of the model. Results are positive after the intervention, statistical differences between pre-test and post-test are found to be significant. The best results are observed on questions related to new physics and the whole intervention has improved the interest of students towards this kind of science. Results also show a better performance when embodiment is directly involved.

6. Contributions and Scientific importance of this work

Considering particle physics concepts as part of High School curricula is barely investigated (Moreira & Ostermann, 2000), although is strongly motivated. In this way, the main contribution of this work is to be the first on proposing a detailed teaching intervention strategy covering those topics, provided an analysis of the current situation (Tuzón & Sobes, 2014; Tuzón, 2014).
On the other hand, the main contribution of the methodology that we propose is the use of embodiment as part of the modelling process. Although used in some other areas (Johnson-Glenberg et al., 2012), the efficacy for building science concepts is not formally investigated. In this way, our work analysis provides positive new results.

7. References

Acher, A., Arcà, M., & Sanmartí, N. (2007). Modeling as a teaching learning process for understanding materials: A case study in primary education. *Science Education*, *91*(3), 398–418. doi:10.1002/sce.20196

Johnson-Glenberg, M. C., Lindgren, R., Koziupa, T., Bolling, A., Nagendran, A., Birchfield, D., & Cruse, J. (2012). Serious Games in Embodied Mixed Reality Learning Environments. In *Proceedings of the Games, Learning and Society Conference* (Vol. 8.0, p. 8). Retrieved from http://egl.lsi.asu.edu/publications/GLS_2012Proceedings_Johnson_Glenberg_et_al.pdf

Moreira, M. A., & Ostermann, F. (2000). Física contemporánea en la escuela secundaria: una experiencia en el aula involucrando formación de profesores. *Enseñanza de Las Ciencias: Revista de Investigación Y Experiencias Didácticas*, *18*(3), 391–404. Retrieved from http://dialnet.unirioja.es/servlet/articulo?codigo=95014

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henrikisson, H., & Hemmo, V. (2007). *Science Education Now: a Renewed Pedagogy for the Future of Europe European Commission* (p. 10). Retrieved from

http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf

Sinarcas, V., & Solbes, J. (2013). Dificultades en el aprendizaje y la enseñanza de la Física Cuántica en el bachillerato. *Enseñanza de Las Ciencias: Revista de Investigación Y Experiencias Didácticas*, *31*(3), 9–25. doi:http://dialnet.unirioja.es/servlet/articulo?codigo=4489861

Tuzón, P. (2014). *Diagnóstico del proceso de enseñanza-aprendizaje de la física de partículas en bachillerato*. Universitat de València.

Tuzón, P., & Sobes, J. (2014). Análisis de la enseñanza de la estructura e interacciones de la materia según la física moderna en primero de bachillerato. *Didáctica de Las Ciencias Experimentales Y Sociales*, *28*. doi:10.7203/dces.28.3599