The hologram as a teaching medium for the acquisition of STEM contents

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Abstract: The aim of the work presented in this article is to assess whether the use of a hologram enhances the meaningful learning of cellular division contents. A pilot phase has been carried out with a sample of students of 4th course of high school education in the town of Logroño, Spain, working with a control group in a traditional way and an experimental group with the use of the hologram. A test of knowledge about cell division contents was answered so as to know if there were significant differences between the results obtained by the two groups. The statistic U of Mann-Whitney of the non-parametric mean comparison test showed that there is a significant difference of 2.55 points, at 0.05 level, between results obtained in both groups. Moreover, there was also assessed the level of motivation and satisfaction when using the tool for the purpose of knowing their opinion for the future use and development of the tool. The results obtained lead us to consider the hologram as a potential teaching medium as well as a highly motivational tool.

Keywords: meaningful learning; cellular division; holographic tool; U of Mann-Whitney test.


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1 Introduction

The importance of science in society requires that teaching methods used in classrooms encourage meaningful learning based on competency achievement. For this reason, sciences concepts have to be taught in such a way that arouse the interest of students in understanding the phenomena contemplated in the world around us. The Science, Technology, Engineering and Mathematics (STEM) pedagogical methodology in the classroom is crucial as it aims to approach interdisciplinary learning based on project resolution. This type of methodology brings important benefits when carried out in an appropriate way, since it allows transferring the knowledge and skills of the student to the real world in which they live, conferring meaningful learning in which motivation plays a very important role.

As Ocaña (2015) mentions, STEM education has been developed as a methodology for the integrated teaching of science and technology from an interdisciplinary point of view taking into account the importance of the engineering approach based on the development of knowledge focused on the real technological problem solving. As Ocaña comments, the benefits of a STEM educational system are the transference of knowledge and skills to real-world problems, the increase of motivation to learn, the long-term retention of contents learned and the improvement of subsequent knowledge-related learning.

It should be noted that the current boom in the use of this methodology is mainly due to the gradual decline of students to choose science and engineering careers, fact that puts at risk the future of innovation in these fields.

Concretely, at about 12 years of age, when students go from primary education stage to secondary education stage, is when a general school failure, lack of motivation and lack of interest in the subjects begin to appear. In science learning, a goal of researches is to learn about difficulties in students experience when trying to understand the concepts due to the fact that the frustration is translated into lack of motivation and decrease in the academical results (Zeidan, 2010; Cimer, 2012; García et al., 2015).

In this sense, the fourth course of secondary education is crucial as it is when students have to decide whether they continue with their science studies or not in the Baccalaureate. It is in this moment when students first see deeper concepts related to biology and as Tekkaya et al. (2001) mentions, genes and chromosomes, mitosis and meiosis and Mendelian genetics are considered as difficult concepts for them.

In the case of cellular biology, the concepts of photosynthesis, respiration, genetics and cellular division are the ones that present the most difficulties. Some examples directly related to cell division are found in the studies of Banet and Ayuso (2000), who concluded that students considered the hereditary information to be just found in the sex
chromosomes, or that the sexual chromosomes are just found in the gametes (Banet, 2000) or the difficulty when understanding meiosis and relating it to the process of gametes formation (Ibañez and Martínez, 2005).

The study carried out by Íñiguez and Puigcerver (2013) based on a methodology to favour the conceptual change in students, concludes that it is necessary to use three-dimensional models and referents as close as possible to the student to enhance their meaningful learning. In the case of mitosis and meiosis, they allude that their study has to be related, focusing more on the global biological meaning than on discerning what happens at each stage of both processes due to fact that if the global process is not understood, even less would the phases. In the case of mitosis, the authors recommend starting from a zygote and explaining the process of cell growth by splitting genetic material between the daughter cells to come to understand that all cells obtained by this process need to be the same. In the case of meiosis, it should be focused from the point of view of the variability between individuals so as to understand that the gametes are haploid cells.

As technology advances exponentially and acquires new educational applications, it is crucial to take into account how it gives a new meaning to learning. In this context, the potential of the hologram in training programs is undeniable especially in science contents learning. The hologram was invented in 1947 by Dennis Gabor, who won the Nobel Prize for Physics in 1971. The idea consists of a three-dimensional photograph executed with a laser beam through an object so that a second ray is projected onto the reflection of light of the first ray, allowing to obtain three-dimensional optical images.

It can be explained that although this technique is not new, the illusory effect that it transmits has become very popular. There have been advances in the holographic projection related with the visual improvement of the technique ‘Pepper’s Ghost’ that was developed in the mid-19th century. Nowadays, this technique is applied with improvements in the quality projection of the image and binocular vision, which makes it an animated hologram almost real to the original.

The technique ‘Pepper’s Ghost’ is based on the fact that the viewer is in the main room but he or she cannot see that there is a compartment hidden under the stage, place where the actor is located. On the top there is a glass or reflecting surface that shows the floating and ‘ghostly’ figure of the actor, as a result of receiving the light that impacts on it and reflects on the surface located on the stage. The room, where the person or object to be projected is placed, should be dark, preferably black, to highlight luminous colours on the reflecting surface.

The prisms are also based on the same ‘Pepper’s Ghost’ technique, with the difference that just a reflective surface is placed on top of a monitor or screen so that the image is seen on the surface. The animated video should have a black background colour so that the image is projected and appears to be floating.

The study of Serra et al. (2009) establishes a pedagogical foundation of how the hologram is a teaching medium considering that it is supported by the principles of general pedagogy. As this study concludes, the student has the feeling that this object is present and he or she is more predisposed towards learning. There are three factors that allow to argue this fact:

a The possibility of such observation facilitates the mental representation and the formation of concepts, laws, etc.
b It allows to obtain the representations based on the relationships between the form and the content.

c Students are able to establish conceptual relationship both of individual and collective character.

Likewise, their motivational potential is projected in the possibility of generating learning contexts among equals that encourage the creation of a shared work environment (Pozo and Monereo, 2009).

Taking into account that the design of technological tools has to be in accordance with the contents to be taught and that this has to take precedence over the use of the technology itself, the studies carried out by Kerawalla et al. (2006) show that the use of technological tools can favour a decrease in the dialogue between students if they are not used properly, that is to say, if they are used just as a visualisation medium. For this reason, it is crucial the training of teachers in the use of new technologies, to encourage students to achieve meaningful learning, fostering collaborative work, for their integral training.

The project of creating an interactive hologram for teaching science or other subjects was inspired by the research papers of Balogh et al. (2006) and their collaborators Agocs et al. (2006). Balogh et al. (2006) made a project in which they used different optical modules that sent light to a holographic display to show a hologram without the need of additional use of lenses. Agocs et al. (2006) used diverse optical modules besides mirrors to obtain certain interactivity.

Other studies have also served as a reference point such as those of Jones et al. (2007), who developed a device composed of a field light visualiser that allows human eyesight of binocular type to be able to see an image formed in 360 degrees. This is possible thanks to a high-speed projector, which transmits images to a mirror with holographic diffuser and electronic circuit to decode digital video signals. As a result, a projection of the object is obtained which can be observed without the need to wear special lenses and which also avoids the restriction of seeing yourself only from a reference point.

Another study related with the tasting of the effectiveness of holograms in education is the one performed by Ghuloum (2010) with 400 teachers. The results showed that educators considered this technique potentially effective in achieving meaningful learning.

It is worth noting that the research works that refer to the use of holograms for educational purposes, derived from the collections of Serra et al. (2009), as well as in Porras’ thesis (2014), are based on analogic or transmission holograms which are in static plates and are not in motion. They deal with interactive holographic applications through posterior projection or mobile prisms whose objective is to create interactive contents of both commercial and institutional applications.

Another study carried out by Lee (2013) comments about how the proper implementation of holograms in classrooms makes students see themselves submerged in a striking environment that makes them to concentrate and build their own learning from their own previous experiences.
2 Objectives

The general objective of the present work is to design a holographic technological tool that contributes to the meaningful learning of cellular division concepts of the students of 4th year of high school education of a school located in the city of Logroño, Spain, and to evaluate their degree of satisfaction after the use of the tool.

To achieve this objective, the following specific objectives have been proposed:

- To identify with a pre-test that minimal notions that the students have about cellular division in eukaryotic organisms.

- To motivate students to create holographic prisms to understand the concept of hologram and observe what their characteristics are. This fact is considered to be important in relation to STEM competences acquisition.

- To evaluate if the degree of meaningful learning has improved after the use of the tool by applying a post-test to both experimental and control groups.

- To collect those difficulties that remain valid after the application of the holographic tool.

- To verify through a questionnaire the user experience of the holographic tool.

- To explain the possible limitations of this study and the proposals for improvement to continue working with the use of holographic tools.

2.1 Research hypothesis

There exist statistically significant differences in the qualifications obtained in both groups (using holograms and without using them as a teaching tool) in the cell division in the sample tested.

3 Methodology

3.1 Sample

For the development of this study, there was taken a sample of 40 students from two classes of the subject biology and geology taught in English language, 20 students from each class, from the 4th year of high school education (14–15 years old) in a school placed in the city of Logroño, Spain.

With 20 of the students we worked in a traditional way, which constituted the control group, and with the other 20 students we worked with the use of the holographic tool. Both groups were homogeneous with each other and it should be noted that these students had no deep knowledge of the contents of mitosis or meiosis.
3.2 Design

It was carried out an exploratory study, given its nature of pilot study of which few works have been developed. The methodology used in this study is quantitative, using quantitative continuous variables, since it is based on the analysis of quantifiable data that are the qualifications obtained in the tests after the development of the experiment. For this reason, it is an experimental design in which it is evaluated if there are significant differences between two groups.

3.3 Information collection instruments

Several types of validated questionnaires have been used to obtain the information required for this project. The questions were of different nature, true or false, multiple answers and short answers. All tests were conducted with Socrative® Teacher® application and answered by students with the Socrative® Student® application on the iPad® Air®.

Firstly, we have worked with a very simple pre-test of ten questions related with the general concepts of cell division so as taste the previous concepts students had (see it at the end of the paper).

After the development of the experiment, a post-test of 30 questions was used both with the control and the experimental group to assess if there were significant differences between the results obtained after the application or not of the tool (see it at the end of the paper). The questions in this questionnaire are related with the concepts that students had to learn related with cellular division in eukaryotic cells fixed by the official curriculum in terms of the theoretical principles of both division processes and their comparison.

The questions are related with the main processes of cell division and they are divided in three groups, those related to the initial moment, those related to the phases and those related to final result of the divisions. It is important to mention that test questions increase in number (1 to 30), the level of difficulty is greater. From question 17 to 30, questions are related to the phases of the process.

Finally, the test about the use of the tool consisted of ten questions to know the opinion of the students in terms of assimilation of contents, motivation and proposals for improvement.

All tests were conducted with Socrative® Teacher® application and answered by students with the Socrative® Student® application on the iPad® Air®.

3.4 Procedure

The work with the control group was in a traditional way so that the teacher explained the concepts and finally there was played a silent video taken from Youtube® of both mitosis and meiosis. The pre-test of previous knowledge about the concepts of division was answered before the explanation of the concepts and both the post-test and the questionnaire about the user experience were answered after the lesson.

For the work with the experimental group, after having answered the pre-test, the holographic pyramidal prisms were assembled, which can show the figure in 360º, having the teacher previously explain the students hot to do it. The videos, that were the same that those used with the control group, were edited with the Camtasia® video editor to be used in the form of a holographic projection.
For the reproduction of the holographic videos, we worked with iPad® Air® and the pyramidal prism was placed in inverted position on them. The prisms were made with polyethylene music and plastic CD cases, using measurements appropriate to the dimensions of the iPad® Air® (2.5 cm of base, 13 cm of base and 8.5 cm of height).

After finishing the activity with the holographic prisms, the content post-test and the questionnaire on the use of the holographic tool were answered. Figure 1 shows the arming process of the prisms and Figure 2 shows the projection result of watching the video with a pyramidal prism.

**Figure 1** Pyramidal prism for a 360° hologram (see online version for colours)

**Figure 2** Holographic projection of metaphase in mitosis (see online version for colours)

### 3.5 Analysis of data

First, the percentages of correct answers from the pre-test for both groups were collected so as to have a notion of what concepts did the students know or although they did not know them, they could get to them easily from their previous knowledge.

For the analysis of post-test results, as we did not work under parametric assumptions and the sample was less than 30 cases for each group, both control and experimental, the hypothesis test performed for the comparison of means in independent groups was the U of Mann-Whitney, (McKnight and Najab, 2010). Its function is the same as the one of the T of student test, but it compares the means of the comparable group ranges. The ranges are a transformation of the scores of the variable analysed to be able to carry non-parametric analysis. The interpretation is similar to an average; a greater range indicates higher values in the results of that group.

The null hypothesis, $H_0$, established that there were no significant differences between the groups and the alternative hypothesis, $H_1$, that there were. In case that the value obtained was lower than the p-value, for a level of significance of $\alpha = 0.05$, the null hypothesis was rejected.
For each of the 30 questions in the post-test, the percentage of hits between the control group and the experimental group was compared, by means comparison. In addition, it has been made an assessment of the concepts that have not been completely acquired after the use of the tool and those that it will be necessary to propose its improvement. Finally, the results of the user experience test of the tool were collected and analysed in a qualitative way.

4 Results and discussion

4.1 Pre-test results

As mentioned, the pre-test consisted of ten questions about very simple concepts related to cell division. Since the students had not seen the processes of mitosis and meiosis in depth before, the qualification obtained in the pre-test was very low. The results showed that 47.6% of the students knew that a human cell has 46 chromosomes and 57.1% that when the cell divides the genetic material is making chromosomes.

In addition, 61.9% of the students knew that the process by which the autosomal cells are obtained is mitosis and 57.1% that the sexual cells are obtained through meiosis. Only 23.8% of the students knew that mitosis consists of a single process of division and meiosis are two consecutive processes and 66.6% considered both processes as cyclical.

In relation to the results of the division processes, 33.3% of the students agreed both premises that during mitosis cells obtained are equal to each other and equal to the mother and during meiosis they are different from each other and different from the mother. There was 23.8% who only knew the certain premise of mitosis. The 33.3% of pupils who knew both premises, only 28.6% concluded that the result in mitosis were two cells of 46 chromosomes and 14.3% that there were four cells of 23 chromosomes. When it was asked to the students to number the phases of mitosis and meiosis none knew to answer properly.

4.2 Results of the traditional post-test and the post-test after using the hologram

The U of Mann Whitney is used when the size of the groups is small (lower or equal to 30 cases), although there are quantitative (in this case the qualification is considered as a continuous variable) dependent variables.

The results of the analysis are presented in two different sub-tables that are shown in Table 1. The first one shows the descriptive results for the two groups analysed. It is possible to identify the average range in the qualification variable of both groups. In this case, the students of the experimental group obtain a higher rank in the qualifications (28.63), compared to 12.38 obtained by the control group. As already mentioned, a greater rank is equivalent to a greater score on that variable. However, to know if these initial differences are significant the second sub-table should be observed.

The rejection or acceptance of the null hypothesis depends on the value of the calculated statistic, in this case U, and its associated probability. In the same way as the rest of the statistical tests, for the results to be significant, that is, to reject the null hypothesis and to affirm the difference between the scores of the dependent variable, the value of that probability has to be less than 0.05.
This indicates that the proposed null hypothesis has a low probability of occurrence and, therefore, should be rejected.

In this case, differences in the dependent variable (qualifications) between the groups can be affirmed. The value of the associated probability is equal to 0.000, less than 0.05 that is used as the margin of error.

The comparison of means test of two independent groups under the non-parametric assumptions, U of Mann Whitney, was carried out with the SPSS statistical program and reported the results collected in Table 1. A higher range indicates which group obtains higher scores in the dependent variable.

Table 1 Results of U of Mann Whitney test for the contrast of means in independent groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Mean rank</th>
<th>Sum of ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>20</td>
<td>12.38</td>
<td>247.50</td>
</tr>
<tr>
<td>Experimental</td>
<td>20</td>
<td>28.63</td>
<td>572.50</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test statistics</th>
<th>Qualification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>37,500</td>
</tr>
<tr>
<td>Asymp. sig. (2-tailed)</td>
<td>.000</td>
</tr>
<tr>
<td>Exact sig. [2*(1-tailed sig.)]</td>
<td>.000b</td>
</tr>
</tbody>
</table>

Notes: ¹ Grouping variable: group.  
¹¹ Not corrected for ties.

As it can be observed, the level of significance obtained is less than 0.05, so the null hypothesis is rejected, concluding that there are significant differences between the two groups, control and experimental.

Table 2 presents the descriptive statistics of both groups. The difference of means of the qualifications between both groups obtained is 2.55 points, which concludes that the use of the holographic tool has improved the meaningful learning of the concepts of cell division in the studied sample.

Table 2 Descriptive statistics of control and experimental groups

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>N valid</th>
<th>Range</th>
<th>Min</th>
<th>Max</th>
<th>Sum</th>
<th>Mean</th>
<th>Estandar deviation</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>20</td>
<td>20</td>
<td>4.83334</td>
<td>2.91666</td>
<td>7.75</td>
<td>115.838</td>
<td>5.7919</td>
<td>1.4639</td>
<td>2.134</td>
</tr>
<tr>
<td>Experimental</td>
<td>20</td>
<td>20</td>
<td>4.22000</td>
<td>5.78000</td>
<td>10</td>
<td>166.840</td>
<td>8.3420</td>
<td>1.1191</td>
<td>1.420</td>
</tr>
</tbody>
</table>

In Figure 3, it is shown the comparison between the correct percentages of response in both tests and in Figure 4 it is shown the difference in percentage between both tests per question.

As Figures 3 and 4 shown, the major differences can be observed from question 17 to question 29 (more than 40%). These results lead us to important conclusions due to the fact that, as mentioned before, the level of difficulty of those questions is greater, so we can deduce that the use of the hologram has enable students to understand these concepts better.
These questions are most of them related to the phases of both cell division processes and their differences. As Íñiguez and Puigcerver (2013) comment, it is important that students understand the global process to know what actually happens at each phase. As results show that students have understood concepts related with the phases better with the use of the hologram than in a traditional way, we can assume that this tool has a great potential for 3D explorations.

The fact of being able to watch the cell in three dimensions in the key moments in which more differences between mitosis and meiosis can be observed has helped students with the understanding and relation of both cell division processes.

4.3 Main difficulties remaining after the use of the holographic tool

It has been considered important to evaluate the main difficulties observed after the use of the hologram with the intention of being able to improve in a future. These difficulties have been distinguished depending if they are related with the initial moment of the cell, with the phases and the events that take place in each of them and with the final or global result of the processes.
According to the initial moment of the cell, one of the difficulties observed is related to how the genetic material is when the cell is going to divide since only 60% of the students have chosen the right answer (when the cell is in the normal state this is in the form of chromatin).

In relation to the number of chromosomes, 20% of students have not chosen the right answer (all the autosomical cells are diploid) and 15% have not understood that the gametes are haploids due to the fact that when they are fertilised they have to originate a diploid zygote.

This percentages of right answers show that students have understand the global processes of both divisions thanks to the visualisation of the cell un three dimensions with the use of the hologram.

Major failures have been observed by differentiating the events that occur in each phase of cell division and by comparing both types of divisions in relation to those phases. 40% of the students have not understood that before cell division the cell has to grow in size, duplicate the DNA and centrosome and increase the number of nutrients and organelles. All have marked the option that DNA has to be duplicated before the division begins, but the processes of growth and duplication of nutrients and organelles have been left, probably because they are not related to the genetic material.

Only 50% of the students have answered that during the prophase the chromosomes are formed, so they have not understood the concept that in the natural state, the cell has its genetic material in the form of chromatin, as mentioned in the first paragraph of this section. At the prometaphase, 45% of the students did not mark any of the processes that are carried out considering 40% of them that in this phase is when the genetic material duplicates.

A percentage of the 40% of the students have left some of the processes that occur in the telophase, but all have answered that the cells obtained are equal to the mother and the 75% have answered that it that occurs at the same time as the cytokinesis.

In order to know if the students had strengthened the differences between the mitosis and the meiosis, two types of questions have been made in relation to the key phases where the main differences can be seen, mitotic prophase and meiotic prophase I, mitotic anaphase and meiotic anaphase I. All students knew that the main difference between the prophase of mitosis and the prophase I of meiosis is genetic recombination but 20% did not point to the formation of tetrads in the meiotic prophase I. In the anaphase, it has been seen that the students have had more difficulty when comparing both processes since 45% of them have indicated that during mitosis the chromosomes go to the poles and in anaphase I chromatids go to the poles.

These facts lead us to consider that is needed to emphasise in these aspects when chosen the video or performing it with the hologram so as students do not leave any of the events that take place. However, as mentioned in the study of Íñiguez and Puigcerver (2013), the failures related to the discernment of the phases are not as important as the compression of the process itself. In the concrete case of the prometaphase, many textbooks omit it and divide the nuclear processes and the union of the achromatic spindle between prophase and metaphase, respectively.

Regarding to the global result of the processes when the students were asked how were the cells formed after the processes of mitotic and meiotic division, 85% and 90% of the students, respectively, answered correctly. 15% of students have answered that
mitotic daughter cells are different between them and different to the mother and 10% that the meiotic daughter cells are equal between them and different to the mother.

By asking students how many chromosomes the daughter cells obtained by mitosis will have on a human being, 15% have mistakenly answered that they will have 23 and the same has happened when they have been asked about meiosis, 15% have answered that 46 chromosomes.

In the case of meiosis, the percentage of success was lower, 45% of the students have marked that after meiosis I each daughter cell will have the half of chromosomes, that is to say, four chromosomes each with two chromatids. In relation to meiosis II, only 40% have marked that each daughter cell will have four chromosomes of only one chromatid each.

This fact leads us to consider that students have had more difficulties with meiosis than with mitosis which is normal because meiotic division englobes more intermediate events. It would be necessary to emphasise in this fact when improving the 3D visualisation with the use of the hologram.

Finally, in relation to the compression of the final result of mitosis and meiosis as a whole by putting a concrete example of a 2n cell with n equal to four chromosomes, only 10% of the students have indicated all the correct options. The remaining 90% have left correct answers. The correct answer that has the highest percentage of hits is in relation to the number of chromosomes and chromatids that each daughter cell has in mitosis. The 80% of the students have marked that they will have 8 chromosomes of two chromatids each.

In this case, it has been observed that some difficulties are remaining when putting a concrete example that leads us to consider that students have difficulties when extrapolating the concepts learnt. It would necessary to emphasise in the number of chromosomes and chromatids in each phase in the video performed with the hologram.

4.4 User experience of the tool

The results of the questionnaire to assess the degree of satisfaction and the experience in the use of the resource, showed that the 60% of the students knew that a hologram is a virtual representation of a real object, 15% answered that it is an illusion, 15% that it is a mirage and 10% that it is a game.

In order to assess whether they really knew what a hologram is based on, they were asked about the scientific basis for the phenomenon of holography, and 85% of the students spoke in terms of reflection of light. On the other hand, they were asked if they had ever seen a hologram and all the students answered that not in real form, but yes in the films and even two students remembered the hologram that was made after the death of Michael Jackson in an honorific concert.

In relation to the experience in the use of the hologram, 75% marked that the part they had liked to most was to see the video with the holographic prism and 25% opted for the construction of the hologram.

The 95% of students considered that holography can be very useful to study science contents, 68.4% because it encourages the process of meaningful learning and 31.6% because it is highly motivational.

In addition to its use in biology, 60% of the students considered that it would be very useful to study molecular models in chemistry, the rest said in physics, mathematics and technical drawing. The 80% of the students see holography as a better teaching tool than
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traditional based on the use of conventional videos or animations and the same percentage said they would like it to become a tool for common use in classrooms and that they would like to know more types of holographic tools.

Students believe that 3D models are very useful in the classrooms to see concepts to learn as a part of reality where they live, so they learning process is more meaningful.

5 Conclusions

The objectives that have been raised in this research have been achieved through the use of the holographic tool. The test of comparison of means shows that there are significant differences between the results obtained in both groups, the control, that has worked with a traditional methodology and the experimental one, which has done it by means of the holographic prism. As a consequence, the hypothesis of the study has been proved.

The hologram has a great potential in the classrooms due to the fact that it is a tool that enables to create collaborative work environments from a constructivist point of view.

The reasons why this tool is thought to be better for science learning than the typical videos and animations is because it has been probed that it has increased the degree of motivation of the students of the sample chosen when working with it due to its impact by the reflection effect of the light and therefore their learning is more meaningful as the attention shown increases.

This fact leads us to consider the potential and effectiveness of this tool as it favours the learning process of science contents, much of them not visible to the eye, like if they were in the three dimensions. The results lead us to agree with those obtained by Lee (2013) due to the fact the students have been submerged in an environment that has allow them to build their own learning.

Moreover, we consider the hologram is believed as a very suitable tool for the acquisition of STEM competences as it allows student to relate different scientific and technological aspects from a practical point of view as the requirements of society will demand them in the future.

The results obtained are consisted with the conclusions (Serra et al., 2009) established in terms that the student has the feeling that this object is present and he or she is more predisposed towards learning. Moreover, As Pozo and Monereo, (2009) comment it has become clear that is motivational potential has encouraged the creation of a shared work environment.

The questionnaires related to the content used, both the pre-test and the post-test, are considered to be adequate to test the effectiveness of the hologram in terms that, when answered, they give us the appropriate information to evaluate the knowledge acquisition in the students. Moreover, the questionnaire related to the user experience has given us the information required to corroborate the increase of motivation in the students when using this tool and the conclusions got by Ghuolum (2010) who points that students see the hologram as a future teaching tool. Students have understood the physical process behind the use of the hologram in terms of light reflection which is has enable them to achieve STEM competences relating concepts in a global context.

It has been verified that there have been some difficulties in understanding certain concepts related to cell division, so a number of improvements are proposed due to the
limitations of this study. On the one hand, one improvement is to get the tool better, to achieve larger prisms to project on larger screens and give more sense of augmented reality. On the other hand, another improvement is to make a video in which the phases of both processes of cell division can be seen simultaneously to favour the comparison between both of them and to make students better understand all the events that take place in each phase.

However, results have shown that students have understand the results of the global processes which, as Íñiguez and Puigcerver (2013) comment, is the most important fact at this level.

As a future perspective, a system is being developed to work with interactive holograms through the phenomena ‘Pepper’s Ghost’ and ‘rear projection’ in which semitransparent sheets are used to work the contents through an interface of interaction using a motion sensor as Kinect. It is also intended to apply this type of methodology in more schools not only with the contents worked in this study, but also with other science and mathematics topics. Another investigation that is being thought to be performed is related to long-term evaluation, to test whether students in the experimental have really understand concepts better than the control group.

References


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