Real Experiments versus Phet Simulations for Better High-School Students' Understanding of Electrostatic Charging

Fadil Ajredini
Neset Izairi
*Oliver Zajkov**

Department of Physics, Faculty of Natural Sciences and Mathematics, State University of Tetovo, Ilindenska bb, 1200 Tetovo, Republic of Macedonia

**Institute of Physics, Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Gazi Baba bb, 1000 Skopje, Republic of Macedonia*
**Corresponding author: zoliver@pmf.ukim.mk*

(Received: 30.12. 2013, Accepted: 03.02.2014)

Abstract
This research investigates the influence of computer simulations (virtual experiments) on one hand and real experiments on the other hand on the conceptual understanding of electrical charging. The investigated sample consists of students in the second year (10^{th} grade) of three gymnasiums in Macedonia. There were two experimental groups and one control group. In one of the experimental groups, called Sim group, the instruction was realized by means of computer simulations. In the other experimental group, called Real group, the instruction was realized by means of real experiments. The difference between pre-test results and post-test results revel that the approaches used in experimental groups give more quality knowledge and skills than the one in the control group. The results in the Real group and Sim group are very similar. There are slight differences caused by the different features of the two approaches. Some differences occur based on the feature difference between real experiments and computer simulations.

Keywords: Virtual experiments, Real experiments, Understanding electricity

Introduction

Students start learning electricity and charging objects in primary school. Nevertheless, they get in contact with these phenomena earlier in their everyday life. This experience is a good start for developing misconceptions. On the other hand, electrical charging is an introduction into new fields. It is a basis for other concepts, like electric field, electrical capacity and capacitors, electric current, voltage etc. This is the reason why students need to have clear understanding of this phenomenon and the concepts related to it and why many researchers find important to investigate students' knowledge and understanding of concepts in electricity in all educational levels (Raduta n.d., 2013; Finkelstein, 2004; Chabay et al., 2006; Stepans, 1996). Demirci finds a significant difference in preconceptions and misconceptions between male and female students (Demirci et al., 2004). Raduta finds that many misconceptions have their roots in the textbooks' representations (Raduta n.d., 2013). The influence of the different teaching approaches on the conceptual knowledge is also investigated by various researchers (Aufschnaiter von et al., 2007; Dilber, 2008; Roth et al., 2000; Mayer et al., 2001).

Computers, with their big potential, became an inevitable element in the process of research-based learning, particularly when the research is based on laboratory experiments. This gives opportunity to bring the education up to a higher quality level.

There are researchers who find computer simulations flexible and adaptable to the different users' style (Podolefsky et al., 2010). The key features of the computer simulations - visualization, interactivity, context and effective use of computations - are particularly effective for helping students to understand the abstract and counterintuitive concepts of certain areas of physics (McKagan et al., 2008). This can only be achieved by following an extensive set of principles for design and layout (Adams et al., 2008a; Adams et al., 2008b)

Our results, and other researches show that experimental work in science education give more quality knowledge, but only if the experiment is structured in a way that allows students to discover physics rules (Auschnaiter von et al., 2007). It can keep the students in higher order level of thinking i.e. analyzing, synthesizing, drawing conclusions etc. At the first step of this process, the students are in a position to analyze the situation (fourth level according to Bloom's taxonomy), synthesize and create a research procedure (fifth level), evaluate the procedure (sixth level). Afterwards, the students go back to the analysis of the results, synthesizing and creation of formula and/or law and evaluate what they have obtained. This is followed by further analysis of the obtained results in a new situation, creation of new research etc. This means that the students are going all the time in the loop of higher order thinking.

The educators use various teaching methods and approaches in order to come to more quality knowledge. Different researchers come to different results. But, we believe that each approach has its own advantage and contributes to different skills and sections of the understanding.

At this point starts the goal of this research: to find out the contribution of real experiments, on one hand, and computer simulated experiments, on the other hand, on the conceptual understanding of charging objects.

Methods and samples

The sample

The sample consists of second grade (10th grade) high school students from gymnasiums in three cities in Macedonia (Skopje, Tetovo and Valandovo). Two experimental groups and one control group were formed. In the first experimental group, consisting of 86 students, teaching was realized by means of real experiments and we will refer to this group as Real group. In the second experimental group, consisting of 81 students, the real experiments were replaced with computer simulations and we will refer to this group as Sim group. Traditional direct teaching was realized in the control group, which consists of 58 students. Pre-testing and post-testing were performed in all three groups and the results from the experimental groups were compared with the ones from the control group.

Students' activities

The students in the Real group were divided into six groups, each consisting of five students. They had to use plastic rod with woolen cloth and glass rod with leather cloth for charging objects and investigate the interaction between variously charged objects. Practically, they had to investigate all the situations that appear in the test. After finishing the activities the students presented the results and discussed them.

The students in the Sim group were divided into couples. They used PhET simulations to do the investigations. The used simulations were *Balloons and Static Electricity* and *John Travoltage*. After they finished the activities, they had a discussion about the results.

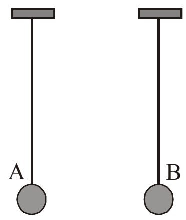
The test

This research is part of a wider research, where the influence of the computer simulations and real experiments on higher order skills was investigated. The acquired knowledge was measured by means of a paper and pencil test. The students' pre-knowledge was pretested and the gained knowledge was measured by posttest after the lecture, where the unit Electrical charging was taught.

The paper and pencil test consisted of eleven conceptual questions. Two of them were multiple-choice questions, where students had to give additional explanation and the rest of them were open-ended questions.

In this research we analyzed only one of the open-ended questions from the test. We decided to single out this question from the rest, because the answer was in the form of a series of drawings. Their analysis can give a deep insight into the understanding of these phenomena. The questions are as following:

Two light neutral metal spheres hang on threads. They are close enough to interact, but they are not in a contact (see the figure). Draw sketches for the following situations:



a) Both spheres are charged by touching with plastic rod rubbed with woolen cloth,

b) The spheres from a) are placed at a greater distance,

c) The sphere A is charged by touching with plastic rod rubbed with woolen clothe, while the sphere B is charged by touching with glass rod rubbed with a leather,

d) Both spheres are charged by touching with plastic rod, but the sphere A is charged more than the sphere B,

e) The sphere A is charged by touching with plastic rod, while the sphere B is neutral

f) The sphere A is charged with glass rod, while the sphere B is neutral.

Results

The answers given in the pre-test reveal that the students in all three groups have almost equal pre knowledge on this issue.

The differences between groups appear after the teaching was performed. The distribution of the students' answers at the posttest, for the situations a) and c) are given in figure 1 and figure 2, respectively.

One can see that the students in the experimental groups have better result in the situation a) than the ones in the control group. While 75 % of the students in the Real group gave correct answers, the Sim group has slightly lower result of 66 % correct answers and the control group has only 43 % correct answers. The distribution of the answers for the situation c) is slightly different from the one for situation a).

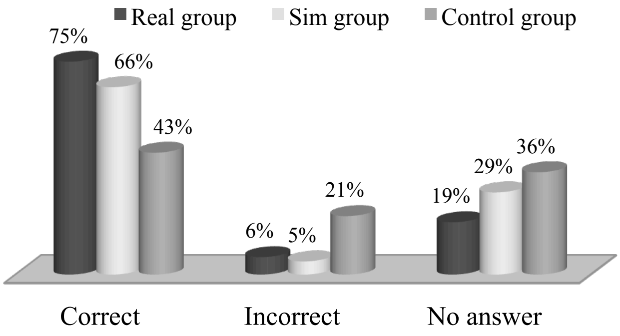


Figure 1. *Distribution of the relative number of answers (in percents) for situation a)*

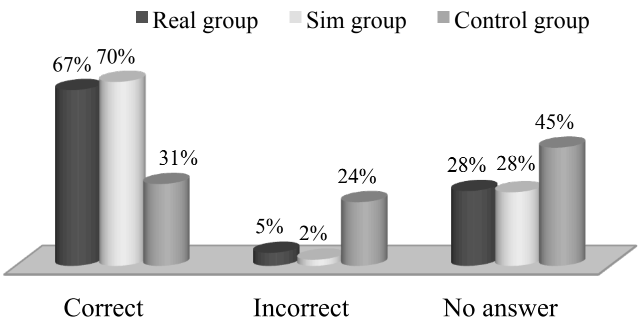


Figure 2. *Distribution of the relative number of answers (in percents) for situation c)*

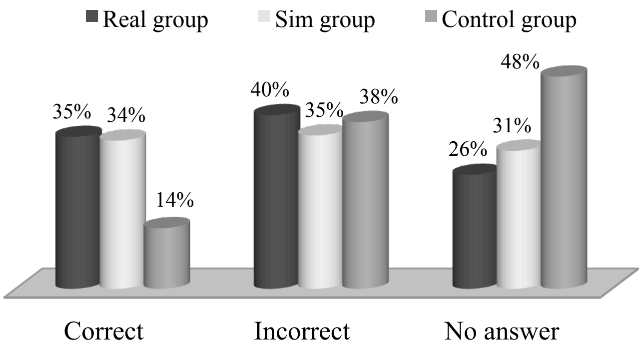


Figure 3. *Distribution of the relative number of answers (in percents) for situation b)*

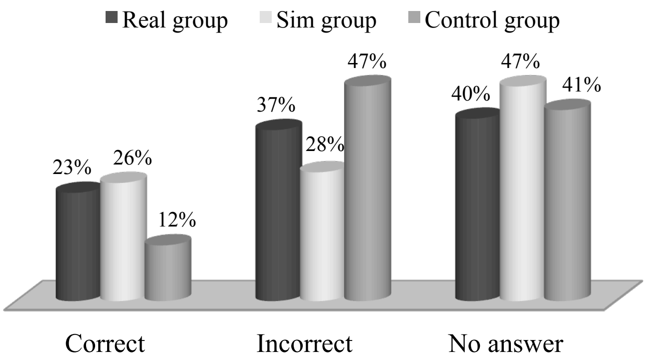


Figure 4. *Distribution of the relative number of answers (in percents) for situation d)*

The percentages of the incorrect answers in the experimental groups, 6 % and 5 %, are very small, compared to 21 % in the control group. In accordance with this, the percentage of students who did not give answers at all is from 19 % in the Real group, 29 % in the Sim group up to 36 % in the control group.

The distributions of the students' answers at the posttest for the situations b) and d) are given in figure 3 and figure 4, respectively. All three groups have much lower achievements at these situations, compared to the results for the situations a) and c). The percentage of the correct answers in experimental groups are halved for the situation b), i.e. about one third of the students gave correct answers, while the control group have even worse result of only 14 % correct answers. The results for the situation d) are even worse. About one fourth of the students in the experimental groups gave correct answers, while in the control group only about one tenth of the students gave correct answers.

Although the relative distribution of the correct answers at the post test between the groups for e) and f) situations is almost the same as in previous questions, it is very much obvious the low achievement of all three groups (figure 5). Only 11 % of the students from the Real group, 7 % from the Sim group and 3 % from the control group gave correct answers, while the percentages of the incorrect answers are 20 %, 41% and 47 % for the Real group, Sim group and control group, respectively. The highest percentage of students who did not give answer is in the Real group.

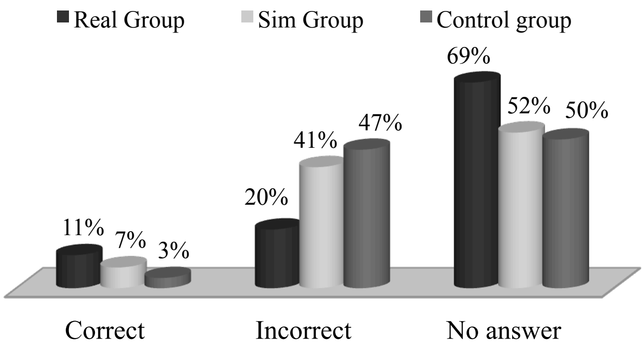


Figure 5. *Distribution of the relative number of answer (in percents) for situations e) and f)*

Discussion

Situations a) and c)

During the discussions with the students, the researchers could conclude that the students knew the Coulomb's Law for electrostatic interaction between electrically charged particles. The students were asked to explain what happened between two charged particles and they were all able to explain that like charges repeal, while opposite, or unlike charges attract. They understand that forces exert on each other. But, when the question is posed indirectly, like it is in this case, then, from the distribution of the answers for situations a) and c) (figure 1 and figure 2), one can see that there is certain percentage of the students who will not give the correct answer. There is a slight difference between Real group and Sim group, but this difference is not something that can give indices for big quality difference between these two groups. Control group has achieved lower result compared to the experimental groups. This leads to a conclusion, that the experiments in the experimental groups, in particular in the Real group, working with woolen clothes and leather, with plastic and glass rods, has left an impression to the students and they have understood the way of charging objects and the role of the different materials during the charging. If we take in account the high percentage of correct answers and the information from the discussion with the students, that all students know that like charges repeal and opposite charges attract, then we can be satisfied with the result.

Students used many different ways to give answers to this part of the question. Figure 6, figure 7 and figure 8 show some of them. Some students used text to further explain the situation (figure 6). When this student answers the situation a), she knows that both spheres are with like charges and denotes them with positive sign, but it is incorrect, because in this case, since plastic rod is used, the spheres are negatively charged. Other marked the distances with symbols (figure 7). There are some students who did not draw the positions of the spheres and treads, but they draw arrows (figure 8). In this case it is not clear are they vectors showing the forces exerting on the spheres or threads, or just directions in which the spheres or threads move.

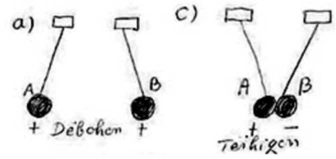


Figure 6. *Different ways of explaining a) and c) situations.*
Translation Left: They repeal. Right: They attract.

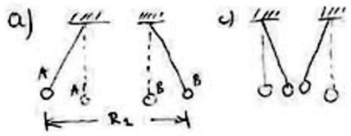


Figure 7. *Drawing showing correct answer of a) and c) situations*

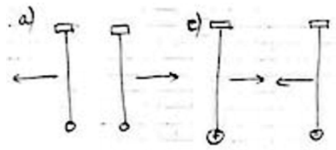


Figure 8. *Drawing showing correct answer of a) and c) situations*

Situations b) and d)

The problem with understanding starts being visible when students have to change something in the situation they have learned at the class. Those are situation b) and d) in the question. The students know the Coulomb's law of interaction between charged particles. They know that in these equation quantities q_1 and q_2 are considered. Although real experiments in the Real group and simulations in the Sim group were performed during the classes, students have difficulties with understanding the dependence i.e. understanding relations. Situation b) tests understanding of the relation between the electrostatic force and the distance, while situation d) tests understanding of the relation between the electrostatic force and the charges. It is not quite easy to design quantitative experiment to investigate these relations. The activities performed during the classes include qualitative experiments, which obviously did not give good enough result. About one third of the students in experimental groups gave correct answers to the situation b). Again, the students use different ways of explaining the situation. Some of them draw the situation and give text with additional explanation, like in figure 9. Others, besides drawing, use mathematical symbol to explain the situation (figure 10).

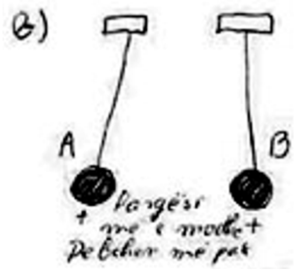


Figure 9. *Answers to situation b). Translation: They repel less*

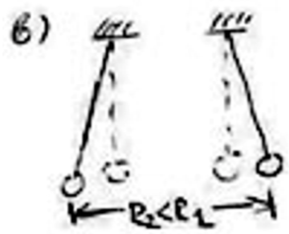


Figure 10. *Drawing showing correct answer of b) situation*

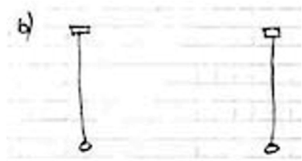
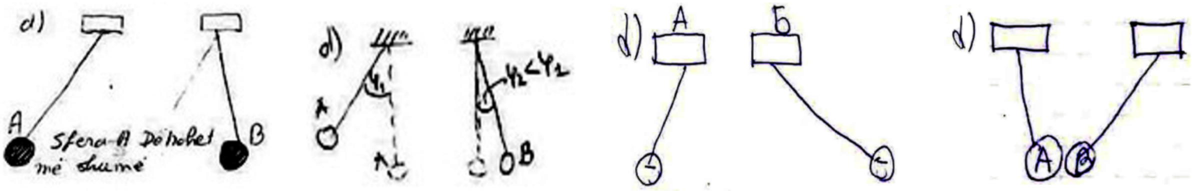


Figure 11. *Drawing showing correct answer of b) situation*

Between 35 % and 40 % of the students in all three groups gave incorrect answer. Almost all of these students draw sketches like the one in figure 11, or similar. Students' answers show that they think if the distance is greater, then the interaction stops. This can be consequence of the experience they have in everyday life. They can see that when the charged object is not close to the other object, then it cannot attract it or repeal it. Their everyday experience tells them that, charged objects have to be close in order to interact. Otherwise, there is no interaction. They forget that electrostatic field extends to infinity and the electrostatic force decreases with squared distance, $1/R^2$. The difference between the percentages of all three groups is negligible. On the other hand, while the percentages of the correct answers in Real and Sim groups are almost the same, 35 % and 34 %, the percentage of correct answers in the control group is only 14 %. Obviously, the real experiments and the computer simulations have equally stimulated the quality knowledge and understanding. There are few answers where drawings do not show any interaction. But, the additional text explains, "the object will repel less, because the objects are placed at greater mutual distance". This answer is combination of correct knowledge and everyday experience. The student draws what can be seen in real life, but also explains with words the things that cannot be seen.

About one quarter of the students in experimental groups gave correct answers for the situation d), which is lower compared to the one for situation b) and much lower than the achievements in situations a) and c). These answers show even more lack of understanding and knowledge. Again, the activities in the experimental groups have stimulated almost the same percentage of correct answers, 23 % in Real group and 26 % in Sim group, while this percentage in the control group is only 12 %. All incorrect answers include versions of sketches shown in figure 12. Most of the incorrect drawings show how the more charged sphere is more declined (figure 12a and figure 12b). There are also answers showing the less charged sphere more declining (figure 12c) or even spheres attracting each other (figure 12d). The discussion with the students reveal that in the later case, the students think that if there is difference in the quantity of the charge, then the objects act like they are with opposite charges. During the class, teachers explains that objects are negatively charged because there are extra negative charges i.e. electrons, while objects are positively charged because there is al lack of negative charges – electrons in the object. This explanation may lead students to think that the objects will attract. But these answers show also a lack of knowledge and understanding of Newton's Third Law. When objects interact, the forces they exert to each other have same magnitudes, but opposite directions. Students forget that the forces exerted on the spheres have equal magnitudes, which causes the spheres to equally decline. Galili also finds that mechanics background influences students' misconceptions in electricity (Galili, 1995) Better results achieved by the experimental groups do not show that the students in these groups know this law better. It simply shows that by experimenting with real or virtual experiments, the students could see the spheres declining equally, regardless of the difference in the quantity of charges on the two spheres. They memorized it and hopefully understood it. During the discussion not any student used Newton's Third Law to explain the equal declining of the objects. However, such situations are good opportunity to remind students of Newton's Third law, to apply it in this situation and discuss with the teacher and with each other.



a) b) c) d)

Figure 12. *Incorrect answers to situation d).*
Translation of the text in a): Sphere A will decline more..

Figure 13 shows some of the correct answers. Figure 13a) shows clear picture of equally declined spheres. There are drawings, like in Figure 13b, which are carelessly drawn and consequently, the drawing implies to incorrect answer. But, in this case there is a text next to the drawing explaining that "they will decline to equal distances". With this additional explanation, the answer becomes correct. This case shows that drawing is not enough. The lack of additional information, obtained in a form of text or discussion students-to-teacher, could bring the teacher to a wrong conclusion about the students' knowledge.

a) b)

Figure 13. *Correct answer to situation d). Translation of the text in b): They will repel at equal distances*

If we take in account that about 70 % of the students for the situation b) and about 80 % of the students for situation d) did not give answers or gave incorrect answers, then we can think of possible misconception. Incorrect answer can be based on incorrect assumptions and information, or on lack of information. If the incorrect answer is based on incorrect assumptions, than we can talk about misconceptions, but if it is based on a lack of information, than it is just a nescience. In this case, we can say that 70 % i.e. 80 % of the students did not have enough information to give any answer. If they had some information, they could process it and give answer. One can say that they have been present at the class, but unfortunately it did not caused interest among these students to listen and to take active part in the class. If the students would give answers, then we would have the necessary data on the students' information and assumptions to analyze the possible misconceptions.

Situations e) and f)

The situations e) and f) had to investigate the understanding of electrostatic induction. Figure 2 shows that the students have achieved lowest result at these two situations. The percentage of students who did not give answers to these situations is the highest of all six situations. This indicates that students did not understand the situation.

In the case of the Real group, we can assume that this is not a misconception, because only 20 % of the students gave incorrect answers, which is a small percentage to draw conclusions on. Very large percentage of the students, 69 %, did not give any answer, means that we do not have any information on their knowledge and understanding of these situations. This can lead to a conclusion that they are not in a situation to process the information and to give correct answer based on a correct analysis and conclusion or incorrect answer based on incorrect analysis and conclusion. They simply do not have enough knowledge and information to make assumptions and to give answer and this indicates the existence of nescience. Similar to the situations b) and d), this can be considered as nescience.

We expected biggest difference between Real group and Sim group for these situations in favor of the Sim group. We thought that the possibility of the simulation to visualize the invisible things would give better results than the real experiments. The simulation *Balloons and Static Electricity* gives students opportunity to "see" the electrical charges redistributing in the wall, when the charged balloon is placed close to the wall. Many of the students usually think that if the charged object is electrically negative, as the balloon in this simulation is, then the positive charges in the wall will be attracted and the negative charges in the wall will be repealed. Probably the main source of this misconception, are the pictures in the textbooks or the drawings that teachers usually draw explaining electrostatic induction (figure 14). More realistic presentation of the process of redistribution of charges can be found in very few learning materials (figure 15 and figure 16). Unfortunately, this opportunity did not initiate any further and deeper students' understanding of electrostatic induction. On the contrary, students in Real group achieved better result than the ones in the Sim group.

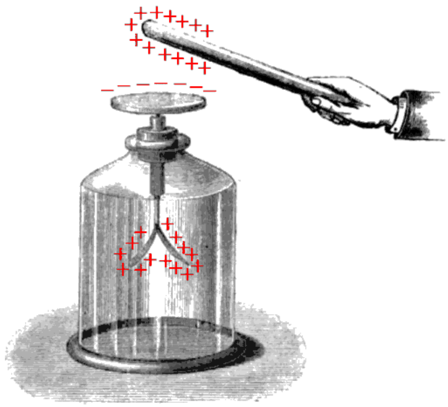


Figure 14. *Incorrect representation of redistribution of charges in the process of electrostatic induction (Wikipedia, 2013)*

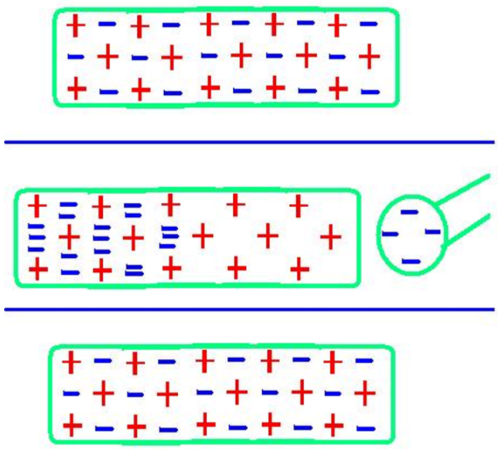


Figure 15. *More realistic representation of redistribution of charges in the process of electrostatic induction (Wikipedia, 2009)*

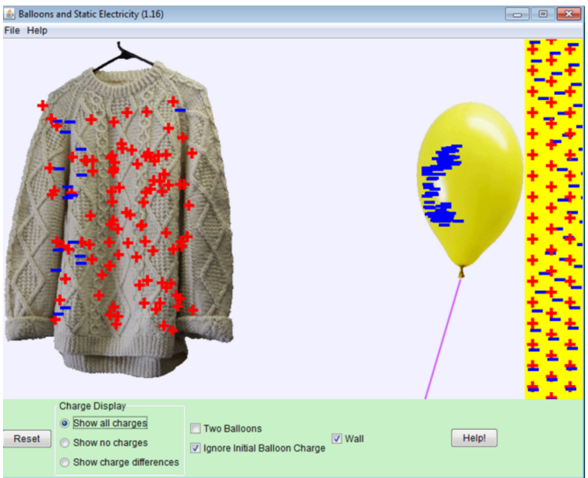


Figure 16. *Redistribution of charges presented in the PhET simulation Balloons and Static Electricity (PhET, 2011)*

Conclusion

This research shows that there is no significant difference between the knowledge acquired through learning supported by real experiments and the one through learning supported by computer simulated experiments. Reasons for this can be searched in various moments of the class:

- Shortage of time – the students had to do all activities (introduction, experiments, analysis, discussion) in only 40 minutes,
- Number of students per group – five to six students in Real group could be too big number to involve each student in all activities and to develop fruitful discussion. On the other hand, two students in Sim group could be too few to create motivating atmosphere for reflection and discussion,
- Directional questions – there is always dilemma on how to pose a question, will it initiate additional thinking process in students' brains, will it develop discussion in the right direction, are the examples interesting enough to provoke the students etc.
- Additional materials for further reading – very often, the experiments in the textbooks are explained, sometimes even poorly, without any directions for performing, analyzing, additional questions or activities. The experiments in the workbooks are often compared with the cookbook recipes, where the students are mainly supposed to follow and execute procedures in order to see and to confirm already known laws, relations and formulas.

However, each of these two approaches gave different contribution, depending on the features they possess. Of course, there is overlapping in developing collaborative and team skills, but, there are also differences. For example, students in the Sim group did not have to spend time on the organizational activities related to laboratory work and problems related to techniques and manual work and they could spend more time on thinking, analyzing and discussing. On the other hand, real experiment made the students thinking more, particularly in the beginning, when they had to design the experimental set up and solve practical problems. Simulations do not require real planning and the technical problem, which are supposed to be solved, are negligible.

Finally, it is the teacher who should be the final filter and corrective. He/she is the one who should ultimately decide which approach to choose, based on the situation in the classroom, the objectives to be fulfilled and the concepts which should be mastered. The teacher should act like a conductor of the orchestra, in which every member is a soloist and requires personal attention in order to give maximum. Students should be put in a situation which requires research approach, analytical thinking, collaboration, making decisions and conclusions, designing new procedures and activities. Teacher should create and design activities on the basis of the experience with the current students, activities which will give better understanding. Discussion with the students should include deeper analysis and explanation of the formulas.

Acknowledgments

The authors wish to thank Prof. Josip Slisko for his kind support and help in writing this article.

References

Adams, W. K., Reid, S., LeMaster, R., McKagan, S. B., Perkins, K. K., Dubson, M., Wieman, C. E. (2008a). A Study of Educational Simulations Part I - Engagement and Learning , *Journal of Interactive Learning Research*, **19** (3), 397-419.

Adams, W. K., Reid, S., LeMaster, R., McKagan, S. B., Perkins, K. K., Dubson, M., Wieman, C. E. (2008b). A Study of Educational Simulations Part II - Interface Design , *Journal of Interactive Learning Research*, **19** (4), 551-577.

Aufschnaiter von, C., Aufschnaiter von, S. (2007). University students' activities, thinking and learning during laboratory work., *Eur. J. Phys*., **28**, S51-S60.

Brekke M., Hogstad, H. (2010). New teaching methods - Using computer technology in physics, mathematics and computer science, *International Journal of Digital Society* (*IJDS*), **1**, Issue 1, 17-24**.**

Chabay, R., Sherwood, B. (2006). Restructuring the introductory electricity and magnetism course. *Am. J. Phys*. **74** (4), 329-336.

Christian, W., Belloni, M. (2001). *Physlets: Teaching Physics with Interactive Curricular Material*, Prentice Hall, New Jersey.

Demirci, N.; Çirkonoglu, A. (2004). Determining Students' Preconceptions/Misconceptions in Electricity and Magnetism. *Journal of Turkish Science Education*, 1(2), 51-54.

Dilber, R., Duzgun, B. (2008). Effectiveness of analogy on students' success and elimination of misconceptions. *Lat. Am. J. Phys. Educ.* **2** (3), 174-183.

Finkelstein, N.D. et al. (2004). Learning physics in context: a study of student learning about electricity and magnetism, Volume 27, Issue 10, January 2005, pages 1187-1209.

Fredlund, T., Airey, J., Linder, C. (2012). Exploring the role of physics representations: an illustrative example from students sharing knowledge about refraction, *Eur. J. Phys.* **33**. 657–666.

Galili. I. (1995). Mechanics background influences students' conceptions in electromagnetism. Int. J. Sci. Educ. **17** (3), 371-387.

Honey, M., Hilton, M. (2011). *Learning Science Through Computer Games and Simulations*, THE NATIONAL ACADEMIES PRESS, Washington, DC.

Mayer, R.E., Heiser, J., Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology*. **93**(1). 187-198.

McKagan, S. B., Perkins, K. K., Dubson, M., Malley, C., Reid, S., LeMaster, R., Wieman, C. E. (2008). Developing and Researching PhET simulations for Teaching Quantum Mechanics, *American Journal of Physics*, 76:406.

PhET (2011) http://phet.colorado.edu/en/simulation/balloons

Podolefsky, N. S., Perkins, K. K., Adams, W. K. (2010). Factors promoting engaged exploration with computer simulations, *Phys. Rev. ST Phys. Educ.*, Res. 6, 020117.

Raduta, C. (n.d) General Students' Misconceptions Related to Electricity and Magnetism, Retrieved on 20th April, 2013 from http://arxiv.org/ftp/physics/papers/0503/0503132.pdf.

Randall, D. K. (2008). *Student Workbook for Physics for Scientists and Engineers: A Strategic Approach*, Second Edition, Pearson & Addison Wesley.

Roth, W.M., Welzel, M. (2000). From activity to gestures and science language. Paper presented at the Annual meeting of the National Association for Research in Science Teaching, New Orleans, April 28th – May 1st, 2000. Retrieved on 20th April 2013 from http://education2.uvic.ca/Faculty/mroth/conferences/CONF2000/JRST110.pdf.

Stepans, J. (1996). Targetiing Students' Science Misconceptions – Physical Science Concepts Using the Conceptual Change Model, Idea Factory, Inc. Riverview, FL.

Wikipedia, (2013), (http://en.wikipedia.org/wiki/Electrostatic_induction)

Wikipedia (2009), (http://ar.wikipedia.org/wiki/%D9%85%D9%84%D9%81:Electrostatic_induction-real.JPG)