The Impact of Additive Manufacturing on Teaching the Archimedes Experiment

Labinot Kastrati[1], Kaltrine Jakupi[2, *], Burim Uka[3], Gezim Hodolli[4]

1. Faculty of Mechanical and Computer Engineering, University of Mitrovica "Isa Boletini", 40000, Mitrovica, Kosovo, labinot.kastrati@umib.net
2. Faculty of Mechanical Engineering, University of Prishtina "Hasan Prishtina", 10000, Prishtine, Kosovo, kaltrine.jakupi@uni-pr.edu
3. Faculty of Biotechnology and Food, UBT College, 10000, Prishtine, Kosovo, burim.uka@ubt-uni.net
4. Faculty of Agriculture & Veterinary, University of Prishtina "Hasan Prishtina", 10000, Prishtine, Kosovo, gezim.hodolli@uni-pr.edu

* Correspondence: kaltrine.jakupi@uni-pr.edu

Abstract: This study aimed to investigate the effectiveness of additive manufacturing-based teaching methods compared to traditional methods for teaching the Archimedes experiment in science education. Results showed that the additive manufacturing method was significantly more effective in enhancing students' understanding of the Archimedes principle and their ability to apply it to real-world scenarios. The customizable and hands-on nature of 3D printing also led to higher levels of student engagement and enjoyment.

However, limitations were identified in terms of the time, resources, and cost required to set up the 3D printing experiment. Despite these limitations, our study suggests that additive manufacturing has the potential to revolutionize science education by providing students with a more engaging, hands-on, and customizable learning experience.

Keywords: Additive manufacturing; 3D printing; teaching; physics.

1. Introduction

Education is a system that consists of a variety of components that collaborate together to accomplish the specific objectives of knowledge transmission and personality development of the individual. It aims to expand the understanding of particular phenomena through the transmission of knowledge from one generation to the next. The educational system ensures that knowledge passed down through the generations is continuously expanded and enhanced, which fosters intellectual growth in society and indicates social progress [1].

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Teaching methods must be designed according to the scientific findings and the characteristics of the field being taught and there are many different teaching method [2, 3]. Unique approaches must be used to ensure that the transfer of information from the instructor to the student has the desired quality. In the exact sciences, experiments play a crucial role in enhancing students' understanding, expanding their creative thinking, improving their teamwork, communication, and discussion skills [4].

However, the rapid technical and technological development has direct effects on the development of teaching at all levels, including for middle school students [5]. The challenge is to ensure that teachers develop at the same pace as technology to improve the quality of knowledge transfer from teachers to students. The demand for modern teaching methods requires additional investments in equipment and training for teachers.

Additive manufacturing (AM), also known as 3D printing, is a rapidly growing technology that has the potential to transform various industries [6], including education [7]. In the field of science education, AM offers new possibilities for teaching complex concepts and enhancing students' learning experiences [8]. One such concept is solid state density, which is a fundamental concept in physics and engineering that describes the relationship between an object's mass and its volume.

The aim of this research project is to investigate the effectiveness of using AM to teach the Archimedes experiment. The experiment is designed to demonstrate the concept of density and buoyancy of solid bodies. It is often introduced in high school physics courses [9, 10].

This experiment is usually conducted in the laboratory setting, where students can observe and measure the properties of different objects made of various materials, such as wood, plastic, and metal, which can sometimes be limited due to the availability and cost of materials.

In contrast, AM allows for the creation of 3D-printed objects with varying infilling percentages [11], providing students with a hands-on experience in manipulating the density of objects. By using AM technology to create physical models of different densities, students may gain a deeper understanding of how density affects buoyancy and why objects float or sink.

The aim of this study is to discuss the realization of the experiment from the subject of physics and to draw scientifically based conclusions about the conventional method of teaching the experiment and the modern method using 3D printing. The same experiment will be applied in both cases, and data will be collected to classify the advantages and disadvantages of the methods under the study.

Overall, this study seeks to contribute to the ongoing efforts to improve teaching and learning in the field of physics, and to explore how new technologies, such as additive manufacturing, can enhance the effectiveness of teaching methods.

2. Materials and Methods

To compare the effectiveness on learning from traditional and additive manufacturing-based teaching methods for the Archimedes experiment, were designed a controlled study. Therefore, were recruited 42 high school students to

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participate in this study, the students were assigned to two groups: the traditional experiment group and the additive manufacturing experiment group. Each group consisted of 21 students, grouped at three sub groups with high, medium, and low achievers based in their previous physics marks. Additionally, the groups were balanced in terms of gender, with 11 girls and 10 boys in each group.

2.1. The experiment for traditional group

It is well known that the classical Archimedes experiment is designed to demonstrate the principle of buoyancy, which describes how objects float or sink in a fluid. The experiment involves immersing an object in water and measuring the amount of water displaced by the object.

Figure 1. The traditional Archimedes experiment kit

According to Archimedes' principle, the buoyant force exerted on an object is equal to the weight of the fluid displaced by the object. This means that an object will float in a fluid if its weight is less than the weight of the fluid it displaces, and it will sink if its weight is greater than the weight of the fluid it displaces. By measuring the amount of water displaced by an object of known volume and weight, the density of the object can be calculated. The traditional experiment group conducted the experiment using pre-made objects of different densities (wood, plastic, and metal).

2.2. The experiment for additive manufacturing group

Additive manufacturing technology were used to realize Archimedes experiment to create objects under the study with varying infilling percentages, which determines their density. This allows students to create objects with precise densities and to observe how the density affects the object's buoyancy. For example, students created a series of 3D-printed cylinders with varying infilling percentages and then

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immerse each cube in water to observe how the amount of water displaced changes as the density of the cube changes. The infilling density parameter of a printed object plays a crucial role in determining its density. By changing this parameter, the density of the object can be controlled. This occurs due to the fact that the volume of the object remains constant while its mass changes. Infilling density refers to the percentage of the internal volume of the object that is filled with material during the 3D printing process. The higher the infilling density, the more material is used, resulting in a higher mass and thus a higher density. Conversely, a lower infilling density will result in a lower mass and lower density. By adjusting the infilling density parameter, it is possible to achieve the desired density of a printed object, which is useful in a variety of applications where specific material properties are required. In addition to the control of density, irregularly shaped printed objects can also make experiments more attractive to follow, particularly when the object is designed to represent a specific person or object. In contrast to standard geometric shapes, the irregular shape of these printed objects can be tailored to mimic the intricate features of a real-life object, making them more realistic and visually appealing.

Also the students have created 3D-printed models with irregularly shaped objects and then measure the amount of water displaced by the object to calculate its density. Much more, 3D printer set up: A personal 3D printer was used with Fused Deposition Technology (FDM) and thermoplastics Polylactic Acid (PLA) as the printing material.

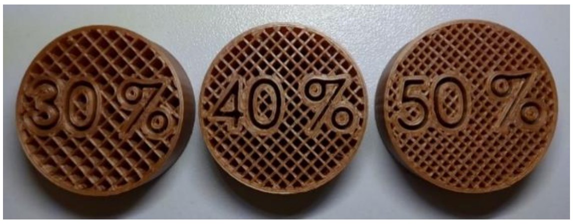

Figure 2. The percentage infilling effect on printed objects

The input parameters were chosen by default, including the nozzle diameter (0.4 mm), print speed (80 mm/s), layer height (0.07 mm), fill pattern (rectilinear), bed temperature (40 oC), and nozzle temperature (200 oC). The only parameter that was varied was the infilling percentage, which was adjusted according to the needs of the experiment (from 15 % up to 100%). This was essential for the Archimedes experiment, as it allowed for the creation of solid bodies with varying densities to explore the concept of buoyancy. By manipulating the infilling percentage, the density of the 3D-printed objects could be precisely controlled, providing a unique and engaging hands-on experience for the students.

After printing the object, the Archimedes experiment can be performed to determine its density by measuring the volume of water displaced when the object is submerged. The use of additive manufacturing technology can provide insights into the relationship between the object's mass and the buoyant force exerted by the

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water. By exploring this relationship, researchers can deepen their understanding of buoyant force.

2.3. Evaluation of students' knowledge

To compare the effectiveness of the traditional and additive manufacturing teaching methods for the Archimedes experiment, were done the same test for both, pre-experiment and a post-experiment for each group. The pre-experiment was done a day before the practical experimental part and the post-experiment was done a week later. The pre-experiment was applied to measure the student's initial understanding of the concept of density and buoyancy, while the post-experiment applied to measure their understanding after the experiment. The test is prepared based on multiple-choice questions, it contain ten most common questions that require students to use their knowledge's of the Archimedes principle. The whole test is presented on appendix A.

To determine if there is a significant difference in learning efficiency between two groups, were used statistical tests, to analyze the results of this study. Firstly were calculated the mean score for each group on the pre-experiment and post-experiment test and compare them using a t-test to determine if there is a significant difference between the two groups before and after the experiment.

Additionally, were calculated the difference in mean scores for each group between the pre- and post-experiment tests and compare them using a depended t-test to determine if there is a significant difference in learning efficiency improvement between pre-experiment and post-experiment for the two groups, separately. Two groups are similar in terms of their characteristics such as the marks of previous stud years, age and gender, to ensure that the results are valid and not biased.

3. Results and Discussion

After conducting pre- and post-experiment tests for both the traditional experiment group and the additive manufacturing experiment group, the value of the parameter p has been independently calculated for each study group. The result of the p-value for dependent t-test for both groups was significantly lower than the recommended value of 0.05 for such studies. This indicates that the knowledge of the students has significantly increased after the experiment for both groups of students.

The distribution of results for the traditional students group and additive manufacturing students groups for pre and post-experiment tests were presented on Figure 3. The meaning of the Figure 3 elements is the red circle = mean value, box = 50% range, vertical red line = 90% range, horizontal red line inside box = median, Extreme black lines outside the box = minimum and maximum values. The p-value of the additive manufacturing experiment group was tens of times lower than the traditional experiment group, indicating that the knowledge gained by the students as a group was higher for the additive manufacturing experiment group than the traditional experiment group.

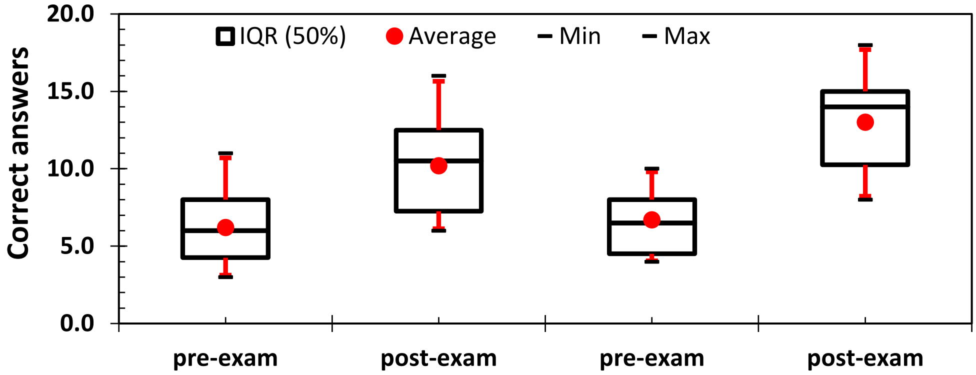

Figure 3. Illustrates the distribution results of the pre and post-experiment tests for the traditional students group and AM (additive manufacturing) students group.

Furthermore, an analysis of the results obtained for each question separately reveals the presence of three distinct groups of questions. The first group of questions showed that students in the additive manufacturing students group achieved better results than the traditional students group. The second group of questions showed that traditional experiment student group achieved slightly better results than the additive manufacturing experiment students group. The final group of questions showed that both students groups achieved similar results. These findings suggest that the additive manufacturing technology as a teaching method effectively increase the quality of teaching-learning process.

Out of the ten questions posed, for both pre and post-experiment, the students who conducted the experiment using additive manufacturing techniques showed greater success. This is particularly evident in questions 3, 4, 6, 7, and 9, which are mostly related to the density of the material of the object in the experiment, Figure 4. Therefore, we can say that the possibility of changing the density of the object led the students to focus more on the effect of density, and as a group, they benefited from a better ranking than the group that conducted the experiment in a traditional way.

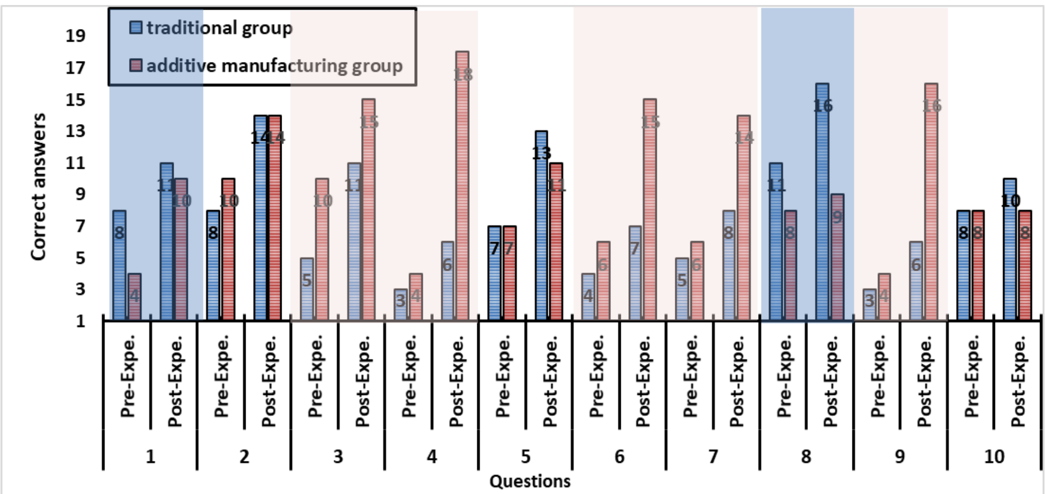

Figure 4. Comparisons of results specifically form each question and testing group.

However, the group of students who conducted the experiment in a traditional way showed the higher success in the tests. They showed success in the first and eighth questions, which are related to the general concepts of Archimedes' experiment. Therefore, we can say that this group showed easy success in only two out of the ten test questions. Moreover, three of the ten questions do not favor either of the study groups. These questions are the second, fifth, and tenth of the tests.

The use of 3D printing allows for the creation of custom objects with varying levels of infill density, providing students with a more hands-on approach to learning the concept of density. This method can also allow for a wider range of materials to be used in the experiment, which can enhance the understanding of the relationship between material properties and density. This allows students to gain a deeper understanding of how density affects buoyancy in real-world situations. However, this approach may not provide students with a comprehensive understanding of the concept, as they may not have the opportunity to manipulate the object's density.

The text continues here.

4. Conclusions

The results showed that the additive manufacturing based teaching method was significantly more effective than the traditional method for teaching the Archimedes experiment. Students in the additive manufacturing group demonstrated a greater understanding of the Archimedes principle and were better able to apply it to real-world scenarios than students from traditional group. Moreover, students in the additive manufacturing group reported higher levels of engagement and enjoyment during the experiment, suggesting that the hands-on and customizable nature of 3D printing enhanced their learning experience.

This study also identified some potential drawbacks of using additive manufacturing technology in the classroom. One limitation was the time and resources required to set up the 3D printing experiment. Unlike the traditional experiment, which required pre-made objects, the additive manufacturing experiment required time to design and print the objects, which may not be feasible for all schools. Additionally, the cost of 3D printing technology and materials may be prohibitive for some schools. Despite these limitations, our study suggests that additive manufacturing has the potential to revolutionize science education by providing students with a more engaging, hands-on, and customizable learning experience.

Overall, this research shows that additive manufacturing is powerful tool with great potential to contribute on the development of innovative teaching methods and improve student learning outcomes in science education.

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Appendix A

1. What is Archimedes' principle?
   a) The principle of conservation of energy
   b) The principle of buoyancy
   c) The principle of relativity
2. What is the unit of measurement for the buoyant force?
   a) Newtons b) Kilograms c) Meters
3. Which of option are correct:
   a) $\rho = \frac{m}{V}$ b) $\rho = \frac{V}{m}$ c) $\rho = m * V$
4. Is it possible for an object to have a varied density for the same volume despite being composed of the same material?
   a) Yes b) No c) do not know
5. If the buoyant force acting on an object is less than its weight, what will happen to the object?
   a) It will sink b) It will float c) It will stay suspended in the water
6. When the volume and mass of objects are the same, would the form of an object influence the buoyant force?
   a) Yes b) No c) do not know
7. If there will be two objects in the water that are made of various materials but have the same mass and volume, what will be the their buoyant force?
   a) The same b) Different c) It is depended by gravity acceleration
8.Explain why a helium balloon rises in air according to Archimedes' principle.
   a) The buoyant force acting on the balloon is greater than its weight because the helium gas inside the balloon is less dense than the surrounding air
   b) The buoyant force acting on the balloon is less than its weight because the helium gas inside the balloon is more dense than the surrounding air
   c) The balloon rises due to the principle of relativity
9. If a solid object has a density greater than that of water, will it sink or float in water? Why?
   a) It will sink because its weight is greater than the buoyant force acting on it
   b) It will float because its weight is less than the buoyant force acting on it
   c) It will stay suspended in the water
10. How can you use Archimedes' principle to determine the density of an object?
   a) By weighing the object
   b) By measuring the volume of the object
   c) By calculating the buoyant force acting on the object and measuring the volume of water displaced.

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