PHYAR: Introducing a Mixed/Augmented Reality Platform for Physics Concepts

Morcos Adly, Nada Nasser and Nada Sharaf
The German University in Cairo, Cairo, Egypt

Keywords: Augmented Reality, Education, Physics, STEM.

Abstract: Physics surrounds each one of us in their daily life. For that reason, it is crucial to teach young students the concepts of Physics gradually starting from earlier ages. The goal of the work presented in the paper is to design a serious game that could help young age children to understand some basics Physics concepts. The centred goal of this paper is the design, implementation, and analysis of an AR serious game that could help young aged students in grasping some basic Physics concepts.

1 INTRODUCTION

Innovation, today, is of a crucial role in our life. It is viewed as a premise of development of an economy. An economy which is poor in innovation can never develop in the future E(Raja and Nagasubramani, 2018).

With the new mobile cell phones and tablets, Augmented Reality (AR) is gaining more popularity. It can actually offer a different way of seeing and understanding (Zarzuela et al., 2013). It is started to affect various fields including training, medical imaging, ... etc. With the widespread of cellphones and their increasing capabilities, AR has also been used for learning (Khan et al., 2019).

In addition, a lot of applications use serious games. A lot of these applications are designed to enhance the skills of young children. In some cases, gamification is also being included with the educational plan (Laine, 2018).

AR is argued to increase concentration for learning since more senses of the students are involved (Fidan and Tuncel, 2019). AR innovation can be seen as an uprade or an enchantment by learners. It mirrors the items papers and make the clearer and more interactive which is appealing to learners (Sahin and Yilmaz, 2020). Studies show that students who used AR technology have achieved significantly higher scores in comparison with the ones who only followed basic teachers' guidance in classroom (Fidan and Tuncel, 2019; Sahin and Yilmaz, 2020; Strzys et al., 2018).

AR was used in different applications related to Physics concepts such as the work presented in (Cai et al., 2013)

The proposed platform *PHYAR* provides a game with educational purposes. It is specifically designed for the user to gain or strengthen his/her knowledge about three main important Physics concepts which are: States of Matter, Light and Gravity. PhyAR combines AR and serious games to provide an attractive and efficient learning platform.

The main aim of this study is to capture the effect of using PHYAR app on students' academic scores in Physics compared to their scores when only exposed to traditional in class learning methods in School.

2 METHODOLOGY

This section includes details about the approach employed to unravel the research question.

2.1 Game Objective

PHYAR game is designed to teach youngsters approximately within ages 9-12 in primary level some crucial physics concepts of paramount importance, specifically three topics, which will be discussed in the upcoming section. Its main goal not only the teaching, but also sticking their learnt information to their minds. That is because the most difficult part is not to instantly understand the taught concept, but is that the memory never misses it as long as possible.

The inclusion of AR technology is the reason for the previous discussed points. Young students got

Adly, M., Nasser, N. and Sharaf, N.
PHYAR: Introducing a Mixed/Augmented Reality Platform for Physics Concepts.
DOI: 10.5220/0010496103380345
In *Proceedings of the 13th International Conference on Computer Supported Education (CSEDU 2021) - Volume 2*, pages 338-345
ISBN: 978-989-758-502-9

used to reading from syllabus books and sometimes see some illustrative figures related. However, it could be more interesting, expressing and engaging to view real-time animated figures and models with interactive user-interface, which gives the user the opportunity to be in control of what he/she wants to experience. Moreover, with physics being the center of the application, AR technology can be thus used to show detailed physics concepts in terms of movements, sequencing and aspect ratios in a professional unforgettable manner.

PHYAR consists of three main scenes:

1. **Matter** section focuses on states transformation (Solid, Liquid, Gas) and how these transformations affect the particles behaviour and arrangement, along with illustration of the type of change whether heating or cooling.
2. **Light** section consists of two main Light concepts which are reflection and shdow.
3. **Gravity** is mainly to differentiate between the behaviour of free fall of any object in space against its behaviour on earth.

The above topics were selected out of many others related physics topics for numerous reasons. First of all, there was a gap for the target age. The target age for users was excluding the age criteria target for PHYAR app that ranges between 9 and 12. Secondly, Matter and Gravity topics specifically were, to the best of our knowledge, never mentioned in any AR app. Light topics were mentioned in (Sahin and Yilmaz, 2020). However, it was designed for older age group with different concepts. Thirdly, the chosen topics Matter, Light and Gravity are the top of schools' physics curriculum for age group 9-12. Last but not least, The above mentioned topics' concepts are AR-friendly in terms of explicitly unveiling every tiny detail about the structures as well as behaviour and reactions.

2.2 Markers

Markers for PHYAR app are unique for the specified age group not only because they contain colorful illustrating shapes, but also they contain picky bullet points for memory located at the back of each marker. Moreover, the chosen markers are easy to handle, replace and play with. That is why **cards** are used as markers.Marker cards' structure for the topics included in PHYAR are shown in Figures 1, 2, 3, 4, 5 and 6 below (Front and Back):

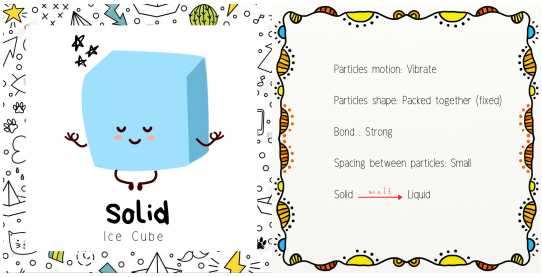

Figure 1: Solid Card.

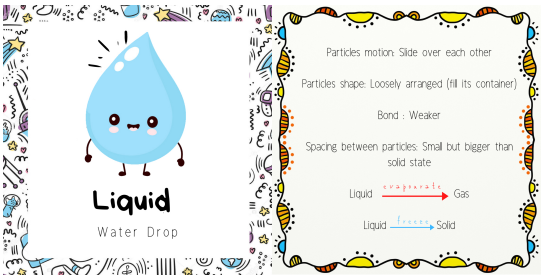

Figure 2: Liquid Card.

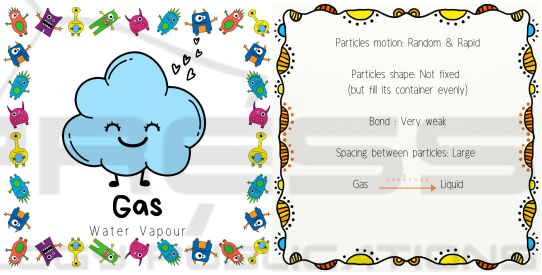

Figure 3: Gas Card.

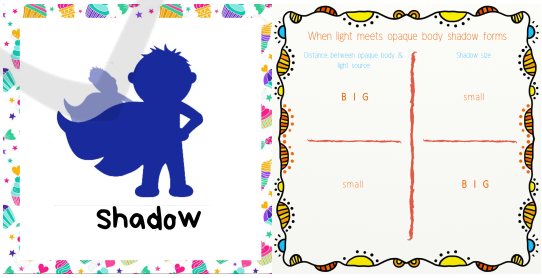

Figure 4: Shadow Card.

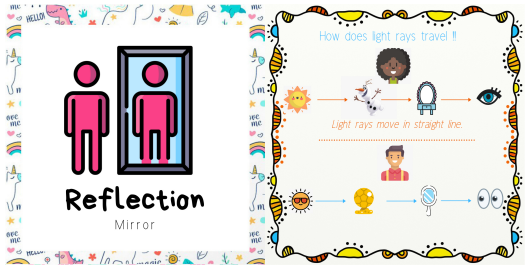

Figure 5: Reflection Card.

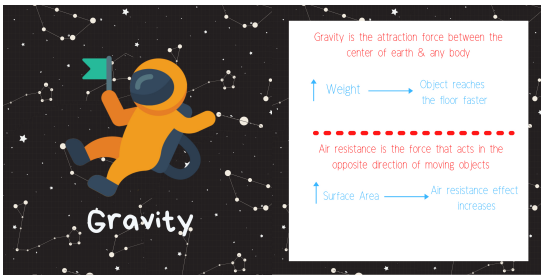

Figure 6: Gravity Card.

3 PHYAR STRUCTURE

The Main Menu page contains three main buttons for the three main topics mentioned before. In addition to an Exit button and Sound On/Off button as shown in Figures 7 and 8:

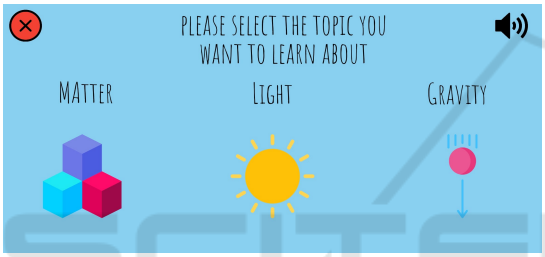

Figure 7: Main Menu.

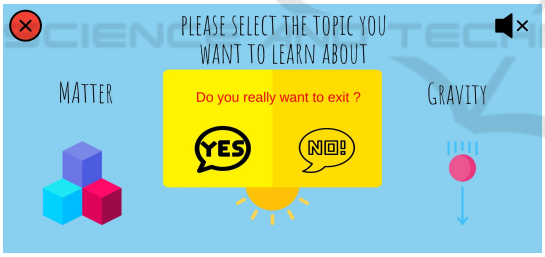

Figure 8: Exit Warning.

3.1 Matter

When Matter button is clicked in the main menu, the Matter Menu appears with those two buttons: 1- Transformation Cycle 2- Random, as shown in Figure 9.

3.1.1 All Transformations

This scene is reached when Transformation Cycle button is pressed. First, the solid card must be detected in order to begin the change of states journey. The ice cube appears first showing the atoms arrangement focusing on their vibrating behaviour by a surprising mobile vibration gesture as shown in Figure 10.

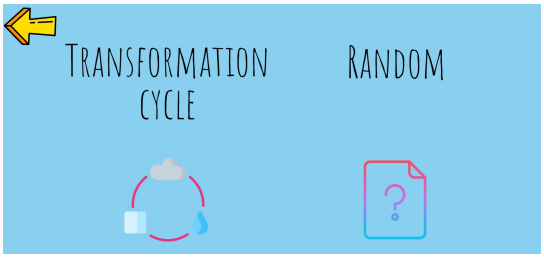

Figure 9: Matter Menu.

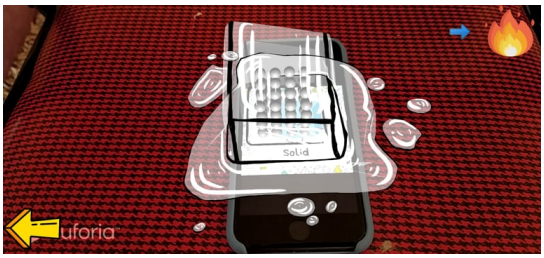

Figure 10: Ice Cube with its Particles.

A melt button of a fire icon can be noticed located at the top right. Whenever it is clicked, the ice cube starts to melt along with the particles starting to move faster and sliding over each other till the ice cube is transformed to water completely. An extra icon of a Snowflake appears at the top left corner which indicates freezing. The fire icon is also visible.however, currently, it indicates evaporation. Giving the choice to the user whether to freeze the water back to ice or evaporate it as shown in Figure 11.

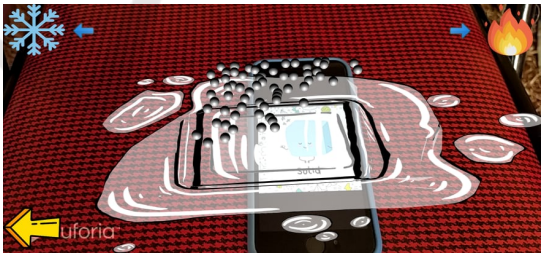

Figure 11: Melted Ice (Water) with its Particles.

If the Snowflake icon is pressed, particles start moving slower and closer to each other forming the ice cube once again with the mobile vibration gesture.

If the Fire icon is pressed, atoms starts to move faster and randomly away from each other till all water vanishes completely forming cloud as shown in Figures 12.

Only the Snowflake reappears indicating condensation of the vapour and once the Snowflake icon is clicked, the atoms slow down and start to slide over each other reforming water.

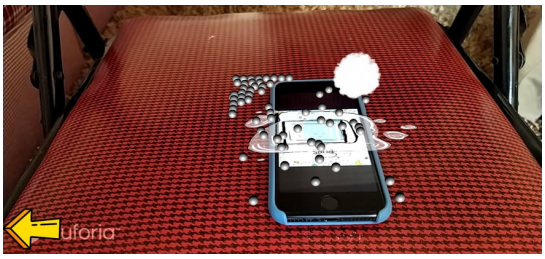

Figure 12: Evaporating Water.

3.1.2 Random

Once the Random button is clicked the user will be asked to detect one of the solid, liquid or gas cards. When each card is detected separately its 3D models appear. Figure 13 is an example when detecting the liquid card.

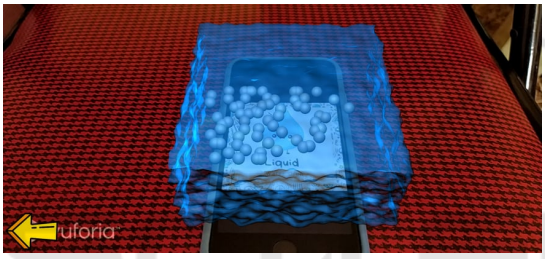

Figure 13: Water (Liquid Card).

3.2 Light

As soon as Light button is chosen, the user will have to choose which light concept to learn about Reflection or Shadow as shown in Figure 14.

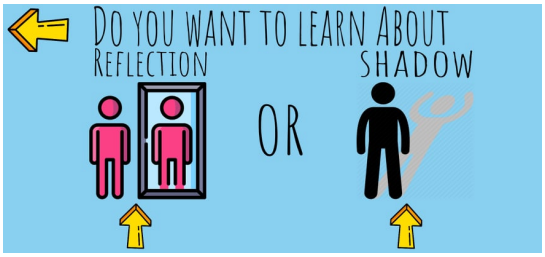

Figure 14: Light Menu.

PHYAR app is customized for both boys and girls. The Light section offers Reflection and Shadow fitting boys/girls interests. This is shown in Figure 15.

3.2.1 Reflection

First, the user must detect the Reflection card. Instantly, a scene consisting of Messi, Ballon D'or, mirror and moon are seen, if boy is chosen. Similarly, if girl is chosen, the user will see Elsa, Olaf, mirror and moon. In both cases, the user can see a Sun icon at the top right corner of the screen and is asked to turn on the light, as initially the moon is up and sun is down as shown in Figure 16.

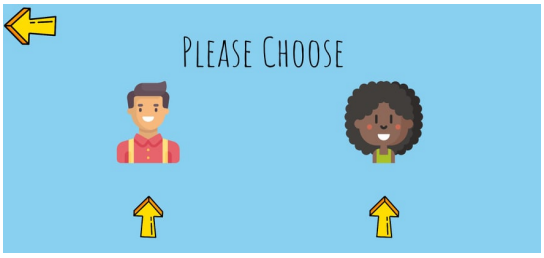

Figure 15: Gender Menu.

Figure 16: Elsa after detecting Reflection Card if the Girl is chosen.

Once the light is on, light rays will be seen travelling from the sun to Ballon D'or/Olaf hitting the mirror then finally reaching Messi/Elsa's eyes. At the same time light reaches Messi/Elsa's eyes Ballon D'or/Olaf can be seen in the mirror. Moreover, Messi/Elsa displays a message and makes a known character gesture indicating that they are happy and the user can turn off the light again by finding the moon icon as shown in Figures 17 and 18.

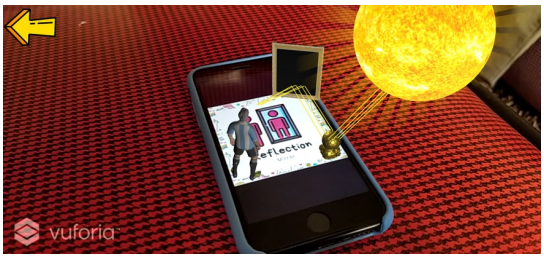

Figure 17: Light Rays journey to Messi's eyes.

3.2.2 Shadow

The user must detect the Shadow card, in order to see Ballon D'or/Olaf, white board and a light source which is a torch. There are buttons for light intensity control and a button to switch on/off light totally.

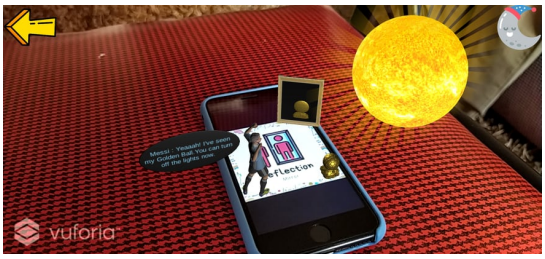

Figure 18: Ballon D'or appears in the Mirror.

As long as light is not off, the user can swipe up to move Ballon D'or/Olaf closer to the torch. Consequently, the shadow size displayed on the white board increases as shown in Figures 19.

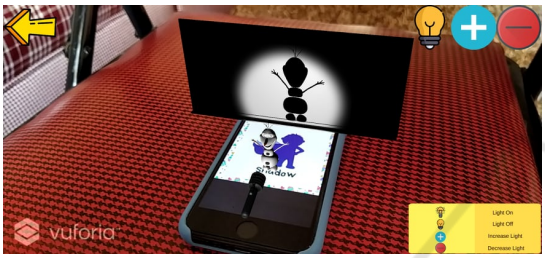

Figure 19: Olaf is close to Torch.

Another option is that the user swipes down to move Ballon D'or/Olaf away from the torch. In this case, the shadow size displayed on the white board decreases as shown in Figures 20.

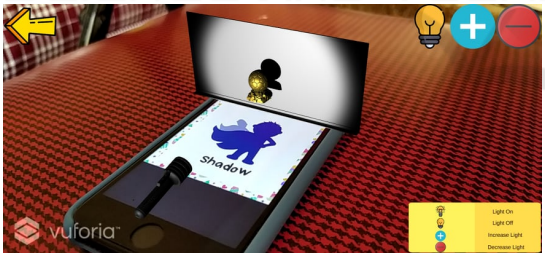

Figure 20: Ballon D'or is far from Torch.

3.3 Gravity

When the Gravity button is chosen, the user is asked to detect the gravity card. Once the gravity card is detected a space scene appears along with an apple and a paper kite. The paper kite and apple positions almost stay the same and they do not fall, as Space misses gravity. An extra button for mode switching from Space to Earth appears at the top right corner of the screen as shown in Figure 21.

If the earth button is pressed, grass appears instead of space. In addition, an audio. saying Gravity on, is played.

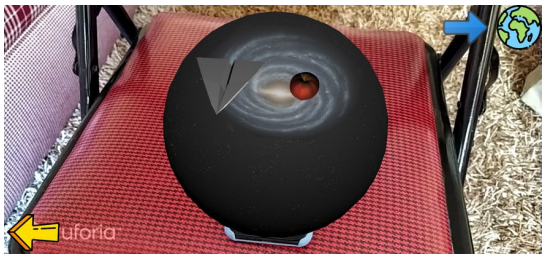

Figure 21: After Garvity Card detection Space appears.

Figure 22: Air Resistance On (Apple reaches the Grass first).

For the gravity scene, all buttons are featured with voice-over to alert the user whether that button's related feature is On or Off.

4 EXPERIMENTAL DESIGN

This section tracks the procedure followed to examine the effect of AR serious game (PHYAR) on students' academic achievements compared to utilizing traditional learning methods.

It was proven by (Repenning and Lewis, 2005) that the learning outcome is not correlated with students' engagement. As a result, each of them were tested as two independent factors.

4.1 Testing Procedure

- **Primary Dependent Variable:** The learning gain of the child.
- **Secondary Dependent Variable:** The engagement level reported during the learning process.
- **Independent Variables:** The only independent variable to be observed is the method of learning, which is AR serious game versus traditional learning.

Hypothesis: AR aided Physics learning boosts students' academic achievements compared to traditional learning methods.

Children were divided into two groups. The **first group** were introduced to the Physics concepts. Af-

terwards, the students of this group had to answer a test about past physics concepts they have already learnt in school which are included in PHYAR game. Students then experience the same content but using PHYAR app. Finally, the students solve the same previous test.

On the other hand, the **second group** solved the Physics test first, then refreshed with the same Physics concepts that they have already learnt before. Then, answering same previous test again. Experiencing PHYAR game comes next followed by last solving phase of the same Physics test that was answered two times before. Some ethical aspects were taken into consideration:

- Having children's parents or teachers permission.
- Giving a clear introduction of the study's main goal before the experiment.

4.2 Evaluation Material Preparing

4.2.1 Pre and Post Tests

There is no difference between the Pre and Post Tests of Traditional Learning and AR, so that the learning gain could be measured correctly. The test contains eleven multiple choice questions presented in hard copy. The questions were divided on the three topics (Matter, Light, Gravity).

All the questions have multiple choices in range four to seven choices, including options like "All of the above" and "Nothing from the above". This options make it more challenging for the students to solve the test. These choices were added to avoid having inaccurate data if the student chooses an answer haphazardly.

The questions were designed to test the students' knowledge and also were opted carefully to examine the crucial parts that PHYAR game covers from the three discussed physics concepts. These two tests' results will be used to carry out the learning gain test, which will be covered in the upcoming subsection.

4.2.2 Learning Gain Test

The Learning Gain Test is the evaluation method used to assess youngsters' academic levels by solving the pre and post test of Traditional Learning method and PHYAR game, which are exactly the same to check the results difference for each child of his/her tests. This difference is how the Learning gain is obtained in order to prove/disprove the research hypothesis.

The Learning Gain of Classical Learning method results are exactly calculated by subtracting the post Classical Learning test from the pre Classical Learning test. Similarly, The Learning Gain of PHYAR results are calculated by subtracting the post PHYAR test from the pre PHYAR test, which is the same result of the post Classical Learning test. For the previous calculated learning gains, if the results are positive this indicates that there is an increase in academic scores of the child whether due to the Classical learning or AR dependably. However,if the results were negative, this indicates that there is a decrease in the academic level. Finally, if the learning gain of the Classical Learning is zero then, Classical Learning has no effect in boosting child's academic level, and the same for the learning gain of the AR.

Finally, the learning gain of both Classical Learning and AR are compared to notice which method has a greater impact on youngsters academic level.

4.2.3 Engagement Test

This study is analysing the engagement level of the child while receiving the educational content using PHYAR serious game app. In order to achieve this goal, a test that aims at measuring the engagement level of the students was utilized using a Likert Scale survey (Pearce et al., 2005).

The questionnaire is composed of 11 measured aspects that evaluate the overall flow of any activity through assessing different major factors: control, enjoyment, and engagement. The questionnaire was answered by the children directly after completing all the Physics topics of PHYAR game. In a nutshell, the results of the measures included in this questionnaire can be summed up to represent the overall engagement, in control, enjoyment levels of using PHYAR app.

4.2.4 System Usability Scale

The System Usability Scale is a basic, reliable survey that assesses the usability of a system. It is formed of 10 Likert scale items (Brooke, 1996). This tool is very helpful for the study as it is important to collect the users' feedback with respect to the usability measures of PHYAR game. It was mainly used to assess the usability of the AR serious game "PHYAR".

5 RESULTS

Most of the children realized that they chose wrong answers while discovering each topic in PHYAR. Others were fascinated by the idea of Elsa and Olaf being part of the Light scene especially girls, and also for the boys seeing Messi and the Ballon D'or.

5.1 Learning Gain

5.1.1 Within-subject Design

The children got an average pre classical learning test score of 3.8 out of 18 points (n=5, M=3.800, SD=0.748), an average post classical learning test/pre PHYAR test score of 7.8 out of 18 points (n=5, M=7.800, SD=1.327), and an average post PHYAR test score 17.2 out of 18 (n=5, M=17.2, SD=0.748). This has indicated a learning gain for the classical method by an average of 4 points (n=5, M=4.000, SD=1.155), and a learning gain for PHYAR serious game by an average of 9.4 points (n=5, M=9.400, SD=0.800) . Figure 23 shows explicitly the comparison between the classical learning method gain and PHYAR gain in group one which shows the p-value significance ($p < 0.05$).

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Gain	Equal variances assumed	3.273	.108	-7.216	8	.000	-5.400	.748	-7.126	-3.674
	Equal variances not assumed			-7.216	6.759	.000	-5.400	.748	-7.182	-3.618

Figure 23: Classical Method Gain vs PHYAR Gain (Group One).

5.1.2 Between Group Design

The children got an average pre PHYAR test/post classical learning test score of 9.6 out of 18 points (n=5, M=9.600, SD=2.059), and an average post PHYAR test score of 17.6 out of 18 points (n=5, M=17.600, SD=0.800). This has indicated a learning gain by an average of 8 points (n=5, M=8.000, SD=2.449).

The following figure 24 shows explicitly the comparison between the classical learning method gain in group one and PHYAR gain in group two which shows the p-value significance ($p < 0.05$).

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Gain	Equal variances assumed	1.185	.308	2.902	8	.020	4.000	1.378	.821	7.179
	Equal variances not assumed			2.902	5.992	.027	4.000	1.378	.626	7.374

Figure 24: Classical Method Gain (Group One) vs PHYAR Gain (Group Two).

There is a significant difference between both tests' outcome. It is obvious that AR aided learning has boosted children's academic scores after using PHYAR app.

5.2 Engagement Level Test Results

The Engagement test results were collected from each student after experiencing PHYAR game, in order to assess its extent for user involvement, entertainment and engagement level while playing. The end result was calculated by getting the average answer of all questions of each user's test, then averaging the previous obtained results. Finally, getting an average answer for all tests which is 4.5 representing 90%.

5.3 System Usability Scale Results

The end average result obtained was approximately 94 which is obviously above the average of 68 according to (sta,).

6 LIMITATIONS

Some limitations were encountered while applying the experiment. To begin with, is the small number of participants of the tested groups. There are two main reasons behind this. The first reason is that COVID-19 spread was during testing time so parents rejected the idea of their child's participation in the experiment fearing from infection. The second reason is that the Augmented Reality technology is not supported by all mobile devices, and we were only capable of providing one device for the experiment; thus, the experiments could not be conducted in parallel or not even sent to be tested at homes and receiving survey results.

The problem of having a small sample was overcome by using the t-tests in evaluating the learning gain as well as the engagement levels because t-tests are useful for analysing data of small samples. However, having a larger number of participants would have assisted in obtaining more indicative results.

7 CONCLUSIONS AND FUTURE WORK

PHYAR app was implemented and tested for the Physics topics Matter, Light and Gravity. An experiment was carried out having two centered goals. The first objective was to obtain the learning gain of each student and the second objective was to monitor engagement levels of students while utilizing PHYAR game. Youngsters were divided into two groups, both were Within-Subject Design, each group contains 5 children of age between 9-12 years.

To evaluate the learning gain, each of the youngsters of the second group was given a pre test before the PHYAR experience, but after some refreshing for the included topics that they have already learnt traditionally in School. In addition to the post test which was given to them after utilizing PHYAR. On the other hand, the first group took an extra test but before the refreshment. The Classical learning method gain of the first group was compared to the PHYAR gain of the first group and second group.

Standardised tests were used to measure usability and engagement.

To sum up, the results revealed the significant positive impact of using PHYAR app, the AR aided Physics learning game, on students' academic achievement. Consequently, PHYAR app has a noticeable effect in Physics learning compared to classical learning method which could be taken advantage of for promoting students' academic level.

The future work could be summarized in three main points:

1. **Extending Physics Topics on PHYAR app:** As currently PHYAR app has three main topics which are Matter, Light and Gravity, there could be a great opportunity for more topics extension. The extended topics could even be suitable for broader age range with varying complexities.
2. **Improving Features and Sound Effects:** Some features like the chosen models could be modified along with the sound effects that could vary with the current scene to be more expressible instead of having uni-toned background music. Most importantly, we can work on increasing the engagement level of the users, so that the application would be more interactive; not only watching scenes but also allowing the students to try and error to increase their learning outcome.

REFERENCES

SUS Score. https://usabilitygeek.com. Last accessed 13 July 2020.

Brooke, J. (1996). Sus: a "quick and dirty'usability. *Usability evaluation in industry*, page 189.

Cai, S., Chiang, F.-K., and Wang, X. (2013). Using the augmented reality 3d technique for a convex imaging experiment in a physics course. *International Journal of Engineering Education*, 29(4):856–865.

Fidan, M. and Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers & Education*, 142:103635.

Khan, T., Johnston, K., and Ophoff, J. (2019). The impact of an augmented reality application on learning motivation of students. *Advances in Human-Computer Interaction*, 2019.

Laine, T. H. (2018). Mobile educational augmented reality games: a systematic literature review and two case studies. *Computers*, 7(1):19.

Pearce, J. M., Ainley, M., and Howard, S. (2005). The ebb and flow of online learning. *Computers in human behavior*, 21(5):745–771.

Raja, R. and Nagasubramani, P. (2018). Impact of modern technology in education. *Journal of Applied and Advanced Research*, 3(1):33–35.

Repenning, A. and Lewis, C. (2005). Playing a game: The ecology of designing, building and testing games as educational activities. In *EdMedia+ Innovate Learning*, pages 4901–4905. Association for the Advancement of Computing in Education (AACE).

Sahin, D. and Yilmaz, R. M. (2020). The effect of augmented reality technology on middle school students' achievements and attitudes towards science education. *Computers & Education*, 144:103710.

Strzys, M. P., Kapp, S., Thees, M., Klein, P., Lukowicz, P., Knierim, P., Schmidt, A., and Kuhn, J. (2018). Physics holo. lab learning experience: using smartglasses for augmented reality labwork to foster the concepts of heat conduction. *European Journal of Physics*, 39(3):035703.

Zarzuela, M. M., Pernas, F. J. D., Martínez, L. B., Ortega, D. G., and Rodríguez, M. A. (2013). Mobile serious game using augmented reality for supporting children's learning about animals. *Procedia computer science*, 25(Supplement C):375–381.