Teaching about the persistence of vision and the sampling rate of the human eye using STEM methodology: An empirical study

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Abstract

Many things around us make sense through the illusion of motion. This fact is based on a 'rawback' of the human eye's function, referred to as '*persistence of vision (POV)*'. This paper focuses on the design, implementation, and evaluation of a project for teaching and experimentally explaining this phenomenon using Arduino and S4A as learning tools in a STEM education framework. Thirty-two (32) pre-service teachers, fourth-year university students, voluntary participated in the research. The aim of the study was to investigate the effectiveness of such educational activities in a STEM methodology framework, the suitability and usability of the tools used as well as the intention of pre-service teachers to adopt such tools and methods in their teaching practice. The results highlight the effectiveness of the tools and the method to achieve the expected learning outcomes as well as the positive views of the participants towards Arduino and S4A as teaching and learning tools in a STEM methodology context and their willing to adopt them in their classroom.

Keywords: STEM Education, Arduino, S4A, persistence of vision, eye sampling rate

Introduction

Nowadays it is commonly accepted that children of 21st century need to be equipped with a variety of skills such as critical thinking, creativity, and innovation to become technologically literate individuals, creative minded persons, and capable solvers of real problems. For this, it is necessary modern teaching methods and tools to be adopted modifying the role of the teacher and the student. The center of such methods needs to rely on interdisciplinary as well as student-centered approaches. The teacher of today is a well-educated person ready to support and promote students' self-action and initiative through creative activities (Karatrantou & Panagiotakopoulos, 2012).

STEM methodology in education serves this learning philosophy and teaching approach and supports the new roles for teachers and students (Lesseig, Slavit, & Nelson, 2017). Within this framework, a particularly useful tool that emerges, is educational robotics along with the different educational packages that are used for the construction and programming of simple automatic control systems (Mcdonald, 2016). The Arduino platform is an open-source platform with a range of uses and applications including educational activities (Przybylla & Romeike, 2015; Omar, 2017).

For the purposes of the present study, simple circuits and constructions with Arduino were designed, constructed, and used to experimentally explain the '*Persistence of Vision (POV)*' and the '*sampling rate*' of the human eye. Primary school pre-service teachers were participated in this attempt working in a STEM education framework. Specially formulated worksheets were used during the project and cognitive tests and evaluation questionnaires were used before and after the process.

Educational robotics & STEM Education

STEM Education

STEM the acronym that derives from the four areas: Science, Technology, Engineering, Mathematics, was first introduced by the Natural Science Foundation. For an educational environment to meet the STEM philosophy, features as the following are needed (Karatrantou & Panagiotakopoulos, 2012): *a content that concerns and finds application in the real world, a student-oriented environment that strongly engages students with the content, a challenging learning process based on research to solve a problem, a Project Based methodology, a learning process inside a collaborative learning model, a process could take place in a controlled and safe environment for students, such as a laboratory, a connection of the four STEM areas making use of knowledge, tools, and methods of them.*

At least during last two decades, worldwide there is a growing concern about science learning in schools. Usually, science curricula are failing to engage students with STEM subjects and STEM careers or develop the critical problem-solving skills needed in professional and everyday life today. There is an emerging recognition of the need to develop authentic school practices in science. STEM and STE(A)M methodology offers possibilities of knowledge transfer between the four disciplines emphasizing disciplinary knowledge as relevant to solving problems. STEM methodology is consistent with competencies that include critical and creative reasoning, complex and collaborative problem-solving, and student agency (Tytler et al., 2021).

Educational Robotics

A particularly important practice, that can combine, make use of, and promote most of what has been mentioned above, is the educational robotics. Students through educational robotics are offered the opportunity to participate in projects and to explore and learn how technology works. As they are engaged in an activity where planning, construction and programming are necessary, students do not only improve their respective skills but at the same time they apply knowledge in practice coming from the subjects of Physics and Mathematics (Omar, 2017). Educational robotics is directly related to STEM philosophy both from a pedagogical point of view and through its direct connection with the two areas of STEM, Technology and Engineering. Educational robotics can also positively contribute to the increase of students' motivation, their engagement in learning, their creativity as well as their positive attitude towards education (Stergiopoulou, Karatrantou, Panagiotakopoulos, 2016).

Many research papers present empirical evidence to support the efficiency of robotics as a complementary tool to learning. The results of learning robotics indicate that students can build computational thinking skills, teamwork, communication skills and collaborative interaction between students and teachers. Educational robotics can offer and support increased student motivation, a sense of fun, enthusiasm, and participation. The literature review present studies that promote the inclusion of programming and robotics in the school curriculum, describing their benefits in terms of motivation, commitment and problem solving. Some studies underline the problems in implementing robotics and programming in schools such as teachers' attitudes, teacher training, logistical issues, and the school resources available (Sáez L opez et al., 2021).

Arduino platform

Arduino is an open-source hardware platform, which incorporates a microcontroller and consists of input and output ports. Arduino could be an important educational tool, as it can support the construction of simple automatic control systems and physical computing. Physical computing is the programming of objects interacting with the natural environment, which in recent years is widely used in all levels of education (Przybylla & Romeike, 2015; Omar, 2017).

S4A is a version of MIT's scratch programming environment, adapted to be able to control the Arduino microcontroller with appropriate commands. In this study Arduino UNO with 'Arduino Starter Kit' and S4A as the programming environment were used. Visual block programming enables experimentation with computational methods that contribute to problem solving, fostering the development of logical thinking skills. Programming is a fundamental science skill, an essential tool to support the cognitive tasking involved in computational thinking, as well as a demonstration of computer competence (Sáez-Lopez et al., 2021).

Human eye and persistence of vision

Persistence of Vision

Persistence of Vision (POV) refers to the ability of the brain to retain a visual stimulus for a short period of time after the stimulus has been lost or altered. Due to POV and to a combination of cognitive functions of the brain described as '*phi phenomenon*' and '*beta movement*' humans can watch animation or cinema, perceiving a sense of motion (Barker, 2009; Cook, 2016). This sense of motion is also known as *apparent motion*. Any image that the human eye receives can be remained for about 1/15 of a second. Thus, if another image is projected during this time, the human brain cannot separate the two images and '*sees'* them as a single image or a visual continuum. Examples where the phenomenon can be observed is the *'visual trace'* which is left behind a lightened object which is being circularly rotated, thus, composing a single circular contour. Another example is '*Newton's disc'*, in which a viewer can see the composition of its colors when the disc is being rotated. Moreover, an example of this phenomenon is the experiment of the '*narrow slit'*. More specifically, if an observer looks through a narrow slit to see an image, he/she can only see a portion of the image at a time. However, if he/she moves the slit quickly, then he/she can get a complete picture of what he/she is looking at, as the visual stimuli received each time through the slit are retained and linked. Some of the constructions built in the 19th century and to which the phenomenon applies are: Thaumatotrope, Phenakistoscope and Zoetrope (Cook, 2016).

Sampling rate of human eye and flicker fusion threshold

The term '*Flicker Fusion Threshold'* refers to the rate at which if a light source blinks its flicker is not visible to the observer, but it looks constantly on. This phenomenon can be observed in a range of frequencies and depends on a set of parameters, such as brightness, retinal position that is stimulated, magnitude of the light source etc. A different frequency of the fusion threshold is observed for different eye cells, rods and cones and their peculiarities. The frequency of the fusion threshold of the rods is estimated at about 15 Hz, whereas this of the cones, depending on the intensity of the light, at about 60 Hz (Cook, 2016). It is, therefore, a phenomenon that substantiates the sampling function of the human eye, since at these frequencies the eye can not perceive the '*off'* mode. This phenomenon is important as it is used in various ways in everyday life technologies. It is directly linked to the projection of static images like, for example, in the cinema. If the rate at which images are displayed is lower than the one required, then the flicker will be apparent. As a result, the movie will not flow smoothly, and the movements will look choppy (Mineault, 2011).

Aim of the study and research questions

The aim of the study was to investigate the effectiveness of the implementation of STEM education methodology using Arduino and S4A as tools to teach the '*Persistence of vision phenomenon*' and the '*sampling rate'* of the human eye. For this purpose, simple circuits and constructions with Arduino were designed and programs in S4A environment were developed to experimentally these phenomena be explained by Primary school pre-service teachers working in a STEM education framework. The research questions were formulated as:

- How Arduino platform can effectively be used and support learning activities in a STEM education context for teaching concerning the persistence of vision and the sampling rate of the human eye?
- What is the intention of future primary school teachers to use Arduino and S4A environment as teaching and learning tools in a STEM methodology framework?

Methodology

The project was carried out in the Computers Laboratory of the Department of Educational Sciences and Social Work, University of Patras. A total of thirty-two (32) pre-service teachers, students of the Department of Primary Education, participated. Ten of them (10) were men and twenty-two were (22) women. The project lasted ten hours in total, consisted of two sessions of five hours each. The thirty-two (32) participants worked in groups of four (4) and the following tools were used for the data collection: *a short questionnaire concerning the characteristics of the participants, paired pre- and post-cognitive tests, an evaluation questionnaire, analyzing data from the four (4) worksheets given to students during the implementation of the project, monitoring and personal notes by the researchers.*

The short questionnaire was consisted of questions concerning sex, age, year of studies, and seven (7) questions with answers in a Likert-type scale concerning students' existing knowledge and skills on computer use, Arduino platform and coding (programming).

The pre-cognitive test consisted of five (5) open-ended questions aiming to assess the existing knowledge about the POV phenomenon, the sampling rate of the human eye and their effect in everyday life.

The post- cognitive test consisted of eight (8) open-ended questions. The first five (5) questions were identical with the questions of the pre-test. The other three (3) questions were focused on the understanding of the activities participants carried out and on the examples of application of POV. The post-test was answered by the participants at the end of the project and after one month as well (follow-up).

The evaluation questionnaire was consisted of thirteen (13) questions. Six (6) questions were open-ended and were concerning students' difficulty while working, their satisfaction with the activities, the knowledge they gained, and the sciences related to this knowledge. The other seven (7) questions were Likert-type with a five-point scale from "None" to "Very much". Students had to answer about their interest in the project, the degree of difficulty of the activities, the educational usefulness of the activities, and their intention to use similar activities in the future for teaching. They also had to answer about the degree of difficulty using the S4A Programming environment and their impressions of the Arduino microcontroller concerning its usefulness and their intention to use it in the future.

The validity of the questionnaires as well as their suitability for the certain project were checked by one expert in STEM methodology in education and one expert in educational technology and appropriate corrections were made.

Four worksheets were constructed and used during the project. The suitability of the worksheets according to the purpose of the project and the research was checked by one expert in STEM methodology in education and one expert in educational technology and appropriate corrections were made.

A pilot implementation of the project with a group of four (4) students took place to check the appropriateness of the worksheets, the applicability of the designed activities, the duration of all the appropriate activities as well as the understandability of the questionnaires by the students.

Three researchers were observing the discussions, activities, and reactions among the students during the whole project. They kept notes and made interventions when students needed help, adopting a supportive and facilitative role of students' work and learning.

For data analysis purposes descriptive and inferential statistics for the quantitative data and content analysis of the answers to the open-ended questions were used for all questionnaires and cognitive tests (Panagiotakopoulos, & Sarris, 2016).

The cognitive tests were analyzed using both qualitative and quantitative data. The content of the answers of the students for each question was analyzed in order to different aspects of their responses to be emerged. Additionally, the answer to each question was graded based on a scale of 1 to 10 according to its correctness. Summing the grades of the questions a total score for each test was derived. The total scores were 50, 70 and 70 points for the pre-test, the post-test after the end of the project and post-test one month later respectively. The tests were graded by two researchers each time to enhance the validity and reliability of the scores based on certain criteria. For the analysis the average scores of the two researchers for each test were used.

Ethics

The research was conducted based on a permit issued by the competent bodies (Council of the Department of Education and Social Work, University of Patras and Region of Western Greece), as provided for by law and the relevant provisions. Students of the Department of Education and Social Work were voluntary participated in the study. During a meeting before the start of the project the purposes and the procedure of the research were analyzed. In any case, the data collection was anonymous, the ethics of the research were fully respected, and the privacy of the participants maintained.

Description of the project

At the beginning of 1st session of the project, the participants answered the short Questionnaire for data collection concerning the characteristics of the participants and the cognitive pre-test. After that, they worked based on the 1st and 2nd worksheet.

Working based on the 1st worksheet students used the Arduino platform and simple electrical and electronic components to create a circuit. The purpose of the 1st worksheet was students to be familiarized with the Arduino, the S4A Programming Environment and to make their 1st experiment as well (Figure 1). They used an RGB LED, a LED that incorporates the three colors: red, green, and blue (Red Green Blue). They designed and created a program in the S4A environment to turn on one of the three colors and then modify it appropriately, reducing the duration of the “on” and “off” state (the blinking frequency). The cognitive goal was to prove and document the sampling rate of the eye, observing that at a certain blinking frequency of the LED the ‘off’ state was no longer perceptible by the eye.

Working based on the 2nd worksheet students had to use the same circuit turning ‘on’ and ‘off’ two colors of RGB LED, the red and the blue one. Students had to create a program to turn ‘on’ and ‘off’ the blue and red color successively and reduce the duration of each state until they cannot separate the two colors observing a purple color (the mix of red and blue). The purpose of this worksheet was to drive students to observe and experimentally be introduced to the phenomenon of POV and the sampling rate of the eye.

During the second session students had to work on the 3rd and 4th worksheet. According to the 3rd worksheet, the participants had to create a more complex circuit using a motor whose rotation frequency was controlled by a potentiometer.

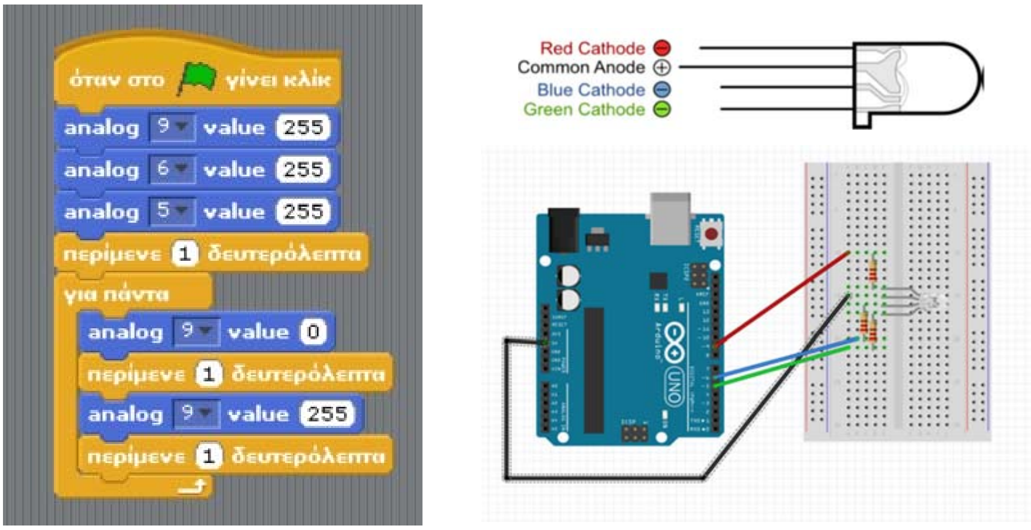

Figure 1. The RGB LED, the circuit and the program for the 1st experiment of the 1st worksheet

As a first task, they had to stick a small thin strip of cardboard onto the motor, put the motor into operation and write down and explain what they observe. In fact, this was an application of POV, during which at a certain rotation frequency of the motor, each position of the rotating strip is held in the observer's brain giving the visual result of a circular disk.

As a second task, students had to simulate the function of the *stroboscope* aiming to be able to calculate the rotation frequency of the motor. The *stroboscope* uses a light source that blinks at a varying and known frequency and at the same time projects its light on a rotating object. When the blinking frequency of the lamp and the rotation frequency of the object are equal the object is perceived as immobile. In this way knowing the blinking frequency of the lamp it is possible to calculate the rotation frequency of the object.

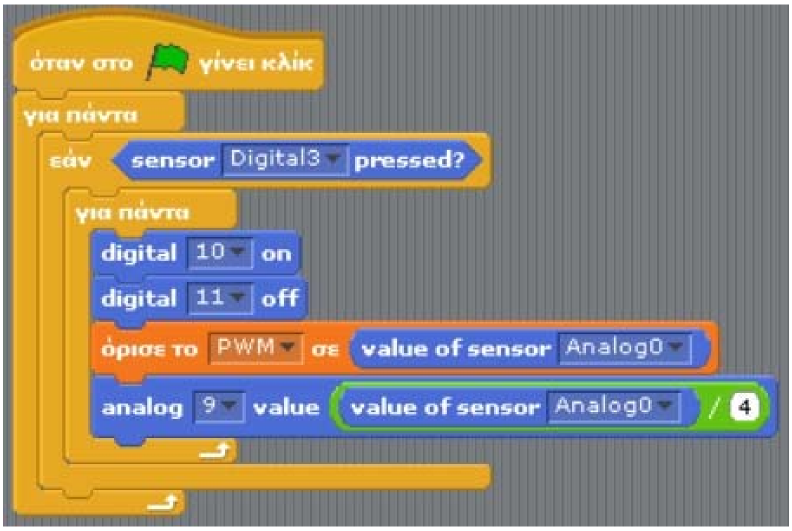

Figure 2. The program for the 3rd worksheet controlling the function of the motor

A simple circuit with a LED and the above-mentioned circuit with a motor used to simulate a *stroboscope* (Figure 3). Students had to change the blinking frequency of the led and write down the value of the voltage at the ends of the potentiometer (that controls the rotation of the motor) at which the strip looks immobile. These values were stored and edited in an Excel file in order to a scatter plot be created. Using this scatter plot participants could calculate the motor's rotation frequency knowing the values of the voltage at the ends of the potentiometer.

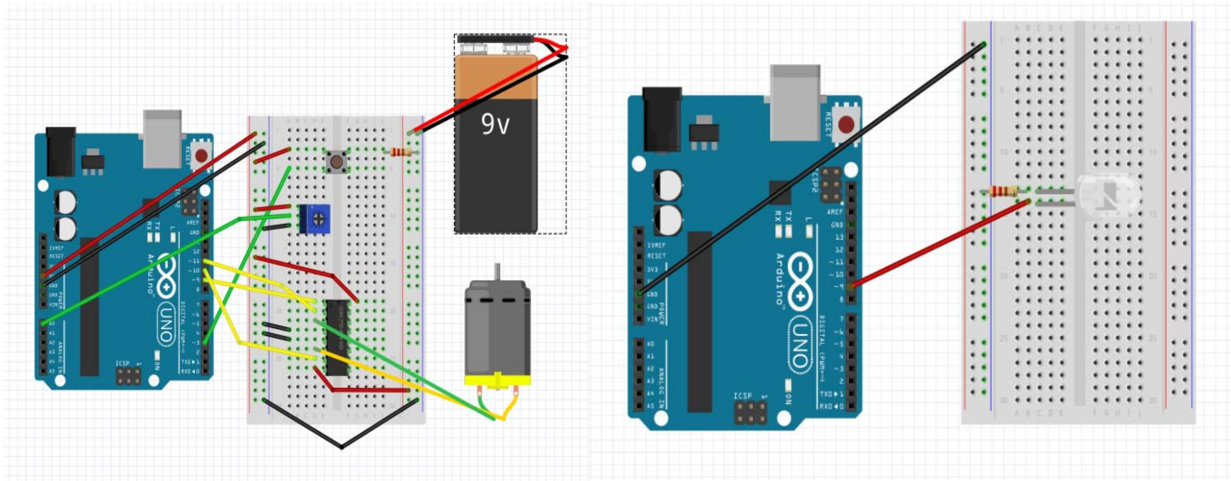

Figure 3. The circuits simulating the *stroboscope* for the 3rd worksheet

At the end of 3rd worksheet, the participants had to reflect on observations they made during the experiment.

Working based on the 4th worksheet, the students use a *Thaumatotrope* and a *Zoetrope* with the help of the circuit with the motor (that of the 3rd worksheet). *Thaumatotrope* is a circular disc with two different images; one in each side and when it rotates it gives as a visual result the composition of the two images. The *Zoetrope* is a cylinder, inside and in the periphery of which there is a series of representations (images) and above them there are narrow slits. When the *Zoetrope* is rotated if someone look through the slits can observe a coherent flow of images taking place, as if watching an animation story. Students using the results of the experiments of the 3rd worksheet carried out experiments with the *Thaumatotrope* and the *Zoetrope* trying to experimentally calculate the rotation frequency at which the above-mentioned phenomena happens and the relation among this frequency, the number of the images on the rotating devices, the sampling rate of the eye and the POV phenomenon (Figure 4).

Figure 4. Students working with the *Thaumatotrope* and the *Zoetrope*

At the end of 4th worksheet, students were asked to create their own animation on a roller. This was an opportunity to create an authentic product using the knowledge they gained.

At the end of the project the cognitive post-test and the Evaluation Questionnaire were distributed. One month later students came to the laboratory to answer the cognitive post-test again.

Findings

Short Questionnaire for data collection concerning the characteristics of the participants

All students had basic knowledge and skills on computer use. Nineteen (19) students had not been involved with coding in the past, while the twelve (12) had been involved with simple programming languages. Most of the students (17) thought that coding is quite difficult (17) and eleven (11) students thought that it is much difficult. Only two (2) students had a previous experience with Arduino (Table 1).

Table 1. Basic characteristics of the sample

	Not at all	Little	Quite	Much	Very much	Sum
Knowledge of Computers Use	1	4	18	9	0	32
Coding experience	19	12	0	1	0	32
Difficulty in coding	0	4	17	11	0	32
Arduino experience	30	2	0	0	0	32

Cognitive Pre-test

Analyzing the answers of the students the following findings were derived.

None of the participants gave a correct answer to what the POV phenomenon is. Only nine (9) students described how an animation works in a way close to the correct one '*animation is a succession of images that have small differences among them and the one comes after the other in a certain rate*'. Six (6) students mentioned only the succession of images. None mentioned that every image remains in the human's brain for a certain period. Most students answered that the eye has a 'rhythm' (20 participants), but without being able to argue this answer or to give an example to prove it. Twelve participants answered that "*the eye is constantly watching*" or noted that they did not know the answer. Students asked about the visual trace that can be observed in an object moving rapidly (application of POV) but none of them could answer correctly: '*It is due to the fact that our eye cannot clearly see an object that runs rapidly and sees only a trace of the object*'. Students called to explain why sometimes '*a wheel rotating in one direction at a certain speed can be perceived rotating in the reverse direction'*. Seventeen students answered in a wrong way or did not know the answer. Five students (5) reported that '*this is an illusion'* and four (4) students mentioned that '*this is due to the speed of the object'*. Six (6) of the participants mentioned that '*the eye cannot follow the speed of the object'* but failed to explain the role of the sampling rate of the eye.

Analysis of the worksheets

Analyzing the data collected from the answers of the students on the worksheets useful finding were derived.

Working with the 1st worksheet, all the groups of students observed that at a specific rate of blinking the RGB LED seemed constantly on. They estimated that this rate is about 50 – 60 Hz. Trying to give an explanation, five of the eight groups explained that '*the RGB LED blinks at such a rate that our eye cannot see the time it is off'*. One team used as an explanation '*the transmission time needed to decode a signal in the brain*', while another combined this explanation with '*the inability of the eye to keep up with the blinking rate of the RGB LED*'. One team mentioned that '*the frequency with which the eye sees is lower than the blinking frequency of the RGB LED*'.

Working based on the 2nd worksheet students had to create a program to turn 'on' and 'off' the blue and red color successively and reduce the duration of each state until they cannot separate the two colors observing a purple color (the mix of red and blue) constantly on. They estimated that this happened when the blinking rate of each color is about 50 – 60 Hz. Trying to give an explanation most teams noted that '*the eye had not enough time to realize the speed of color change*'. The answer of one group managed to approach the phenomenon of POV writing that: "... *the blue color reaches our eye before the red color disappears from our brain and so we see the purple color.*" Two of the groups mentioned that: "*That the LED stops flickering in our eyes is due to the sampling function of the eye ...*" and "*the sampling rate of the eye is equal to the succession rate of the colors*".

After discussing the phenomena and based on their experiments students calculated the sampling rate to be 50Hz and the duration of the POV more than 20ms.

Working on the 3rd worksheet, the participants had to create a circuit using a motor whose rotation frequency was controlled by a potentiometer. As a first task, they had to stick a small thin strip of cardboard onto the motor, put the motor into operation and write down and explain what they observe. At at a certain rotation frequency of the motor students could see a circular disk. The explanation that was mostly given by the students contained the term of POV (7 groups) and six (6) were able to better understand the phenomenon and explain it.

During the 2nd task students constructed a *stroboscope* to create a graphical representation of the correlation between the voltage at the ends of a potentiometer that controls the rotation of a motor and the rotation frequency of the motor. All the groups reached the conclusion that the relationship is approximately linear, and a straight line could describe this relationship satisfactory (Figure 5).

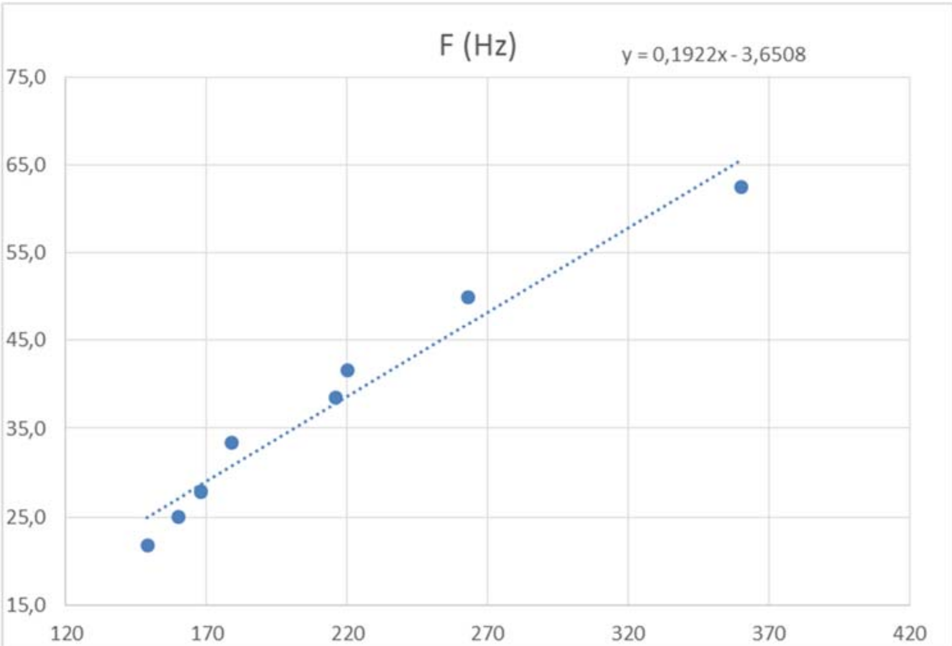

Figure 5. One of the graph representations of the relation between the voltage at the ends of a potentiometer and the rotation frequency of the motor

Working on the 4th worksheet most of the groups (5 groups) were able to explain the function of the *Thaumatotrope* using the terms of sampling rate of the eye and POV phenomenon. Experimenting with the *Zoetrope* all the groups watched the '*animation'* story, and four 4 groups were able to give a good explanation.

Each students-group calculated the frequency of the motor at which they were observing the above-mentioned phenomena and calculated the number of images perceived per second by the human eye. Thus, the sense of motion or apparent motion was discussed.

The last task of the worksheet concerned the construction of a personal animation on a cylinder by each group, which, due to lack of time was not completed. However, all the groups designed heir animation and explained the way that it would be working.

Cognitive Post-test

Analyzing the students' answers at the cognitive post-test after the end of the project interesting findings were derived. Twenty-three (23) students described correctly or almost correctly what the POV phenomenon is. Characteristic answers are: '*is the ability of the brain to hold an image for some time*', '*is the process whereby, in our vision, we see an image we retain and then a second image is added, and so we see them mixed or in continuity*'.

Thirteen students answered correctly about the function of animation and most of the others enriched their answers in the correct direction in comparison with the ones in the pre-test. Characteristic answers are: "*Animation is a series of successive images with small differences between them which are projected at such a rate that we can see them clearly and, at the same time, taking advantage of the effect of POV, to perceive a flow, a story onwards*". All students answered correctly about the rate of eye sampling and its documentation. Eighteen (18) of the students answered by giving an explanation and nine (9) of them documented their answer with an example or made references to numbers that were calculated in the experiments. Ten (10) of the participants explained the visual trace that can be noticed in a fast-moving object referring to POV or its description. Characteristic answers are: "*Because of the fast motion, the eye's frequency sees the subject at various points, and because of its presence it retains previous images, and instead of appearing as an object at every point it seems unified*."

Students called to explain why sometimes '*a wheel rotating in one direction at a certain speed can be perceived rotating in the reverse direction*'. Although few (7) of the participants responded correctly according to what was discussed, most of them tried to give an explanation thinking in a correct way but ending to wrong results. Indicatively: "*When the motor's frequency is greater than that of the eye, then the impression of the reverse motion is given*." Fifteen students correctly explained the phenomenon of mixing colors in the RGB LED and seventeen (17) mentioned the term of POV without giving a further explanation. Eleven (11) students correctly described the function of the *Zoetrope.* Most of the participants (27) mentioned at least one example of application of the POV phenomenon and fourteen (14) mentioned examples linking the phenomenon to everyday life. Indicative answers: "*movies, cinema, moving electronic labels…*".

The answers of the students at the cognitive post-test one month later (follow up) were similar with the ones just after the end of the project. Based on this we might support that student retained the knowledge and experience gained during the project supporting this way the educational value of the method and the tools used.

Evaluation Questionnaire

Answering the questions of the evaluation questionnaire participants had to write down what difficulties they faced, what they like more during the project, what new they think they learnt, how interesting and useful they found the project and the tools they used as well as their intention to use them in their teaching practice.

Almost all students liked the project and the tools used. They liked the way they worked combining theory and practice using experiments. Many students answered that they needed more time for the project. Most participants answered that they learnt about new concepts concerning the physiology of the human eye and applications of them (80.65%). Many participants answered that they were familiarized with coding (58.06%) and making constructions (41.94%) either Arduino circuits or animation applications. Some of them answered that they gained knowledge about the teaching approach (9.68%) used (STEM methodology) as well as the importance and applicability of educational robotics (6.45%). Most students mentioned that they used knowledge mainly from the fields of Physics, Technology and Mathematics. Some of them mentioned Engineering. Most students answered that the new knowledge gained concerns Physics and information Technology, while some others mentioned Mathematics and Engineering as well.

Participants had also to express their opinion about the project by answering questions with answers in a range of '*Not at all*' to '*Too much*'. Most students found '*much* to '*very much'* interesting the activities they carried out, although about half of them described the activities as quite difficult. The majority of the students also answered that the activities had a '*much* to '*very much'* educational value and that they would adopt such activities in their teaching practice. Many participants noted that they had a little difficulty with the Scratch for Arduino programming environment (S4A) and seemed particularly keen on using Arduino as a useful educational tool (Table 2)

Table 2. Evaluation questionnaire

Questions	*Not at all*	*A Little*	*Quite*	*Much*	*Very much*	Sum
Activities were interesting	1	2	2	10	16	31
Activities were difficult	2	9	16	2	2	31
Activities were useful in teaching	1	3	6	10	11	31
Adoption of activities in teaching practice	1	4	6	11	9	31
Difficulties using S4A environment	3	19	7	2	0	31
Usefulness of Arduino in teaching practice	1	1	8	13	8	31
Intention to use Arduino in teaching	0	7	3	13	8	31

Comparison between pre and post tests

As it is described in the Method section, the answer to each question of the cognitive tests was graded based on a scale of 1 to 10 according to its correctness. Summing the grades of the questions a total score for each test was derived. The total scores were 50, 70 and 70 points for the pre-test, the post-test after the end of the project and post-test one month later respectively. The tests were graded by two researchers each time to enhance the validity and reliability of the scores based on certain criteria. For the analysis the average scores by the two researchers for each test were used.

The Shapiro-Wilk test was used to check the normal distribution of the data. Based on the results of the Shapiro-Wilk test the data of the cognitive tests were normally distributed so the paired student's t test was used to compare the mean values of pre and post tests and the student's t test for independent samples to compare the mean values of the tests for men and women. The scores of the post-test after the end of the project were statistically significant higher than the scores of the pre-test (mean difference = -18.0726; $t(30) = -10.993$; $p < 0.001$). The scores of the post-test one month later are not statistically significant different than the scores just after the end of the project ($t(26) = -1.264$; $p > 0.05$). Comparing the scores between men and women no statistically significant differences found concerning the pre-test ($t(30) = .866$; $p > 0.05$), the post-test after the end of the project ($t(29) = .892$; $p > 0.05$) and the post-test one month later ($t(25) = -0.603$; $p > 0.05$).

Discussion and Conclusions

The aim of the study was to investigate the effectiveness of an educational project in the frame of STEM education methodology using Arduino and S4A as tools to teach the '*Persistence of vision phenomenon*' and the '*sampling rate'* of the human eye to primary school students. For this purpose, simple circuits and constructions with Arduino were designed and programs in S4A environment were developed to experimentally these phenomena be explained by Primary school pre-service teachers. A total of thirty-two (32) pre-service teachers, students of the Department of Educational Sciences and Social Work, participated in the research. The project lasted ten hours in total, consisted of two sessions of five hours each. The research was aiming to give answers to two research questions:

According to the 1st research question: *how Arduino platform can be effectively used and support learning activities in a STEM education context for teaching concerning the persistence* *of vision and the sampling rate of the human eye?*

Based on the results of the data analysis coming from all the research tools of the study it can be supported that the participants familiarized with the POV phenomenon and the description of it as well as with the sampling function of the human eye. They recognized applications of POV phenomenon and sampling function of the human eye and were able to give examples from everyday life. It is important that they were able to recall the knowledge they had acquired when asked again in the follow-up questionnaire. Thus, it seemed that what they learnt during the project was maintained at least for this period. We can therefore argue that the specific educational activity using Arduino platform and S4A programming environment can support the achievement of the expected learning outcomes. Participants' answers on the questions of the cognitive tests have shown that they have gained a good understanding of the concepts and the phenomena as well as of their explanation, description, and applications.

Pre-service teachers familiarized with the use of the Arduino platform, the design and construction of circuits and systems and its applications as well as with the programming environment of S4A. Although, participants had not used the tools in the past, it seemed they did not face any difficulties concluding that the tools were particularly supportive of the educational process. Participants using Arduino platform and S4A programming environment manage to carry out experiments, collect numerical data, process the data, and link theory with praxis proving phenomena, procedures, and applications.

According to the 2nd research question: '*what is the intention of future primary school teachers to use Arduino and S4A environment as teaching and learning tools in a STEM methodology framework?*'

The answers of the participants - as future teachers, show their attitudes to be positive in adoption such teaching approaches in their classroom. Both in their written responses as well as in their oral discussions they expressed a very positive attitude towards the educational intervention they carried out and seemed willing to adopt similar practices. Having this experience, they seemed enthusiastic and willing to be engaged in the future with similar activities recognizing the educational value of STEM education methodology and Arduino platform with the S4A programming environment particularly important.

The conclusions of the research agree with other research studies concerning STEM methodology and educational robotics (Alimisis, Karatrantou, & Tachos, 2005; Karatrantou, & Panagiotakopoulos, 2012; Tytler et al., 2021).

The results of this research indicate that the use of robotics in primary schools can well contribute to the learning environment. According to the literature, teachers in accepting new technologies have both attitudes, positive and negative. At the same time, epistemological design challenges and key pedagogical design features are emerging as necessary to support the adoption and integration in school practice (Sáez-Lopez et al., 2021).

The present research aims to contribute to the debate regarding the impact of STEM methodology on school performance in primary schools focusing on the use of educational robotics. STEM Education methodology gradually is exploited in all educational levels worldwide. However, in Greece there are still many obstacles regarding the adoption of both STEM methodology and educational robotics in school practice. Although the findings presented in the study are promising, it is important to point out that the results should be considered under certain restrictions, due to limited sample size. It is important in the future to conduct similar research studies with a larger sample of participants from both populations of pre-service and in-service teachers, so that the generalization of the results to be possible and the results to be more valid and reliable. Further empirical research must be conducted to examine matters related to the obstacles for the integration of educational robotics and STEM methodology in teaching and learning science.

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