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TEACHING ASTRONOMY USING MONUMENTS OF CULTURAL HERITAGE: THE EDUCATIONAL EXAMPLE OF "HOROLOGION OF ANDRONIKOS KYRRHESTES"

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ABSTRACT

The aim of this work is to reveal the benefits arising from understanding cultural heritage issues through STEAM (Science, Technology, Engineering, Arts, Mathematics) education. Further aim is to motivate Greek teachers to combine cultural issues teaching integrated with STEM disciplines so as to give a boost to the reform of the curriculums of subjects taught in Greek schools of secondary education in the direction of interdisciplinarity.

To this direction, arts and cultural heritage should be integrated in the educational process and subject such as Mathematics, Physics and History should be taught in a STEAM educational approach so that students' creativity and innovativeness may be boosted. A very good example of the role that cultural heritage may play is the Horologion of Andronikos Kyrrhestes, an ancient building in the Roman Agora of Athens which has recently recorded as an astronomical monument of cultural heritage by UNESCO. This monument can be used in the educational process for teaching subjects through STEAM activities, due to the interdisciplinary nature of knowledge (e.g. astronomy, geometry, architecture, sculpture, engineering) that was needed for both its construction and function. In this respect, a purposive sample of teachers who teach different subjects in public schools of secondary education in Greece was selected and semi structured interviews were designed recording teachers' opinions about STEAM education using as example the "Horologion of Andronikos Kyrrhestes" monument. The results of this research are presented here.

KEYWORDS: STEAM, cultural heritage, Horologion of Andronikos Kyrrhestes, Tower of Winds, Greek astronomical monuments, teaching astronomy, UNESCO

1. STEAM: AN EDUCATIONAL APPROACH TO LEARNING SCIENCE

STEM is an educational approach to learning that uses Science, Technology, Engineering and Mathematics (Bybee, 2010); STEAM is an educational approach to learning that besides the STEM disciplines uses the Arts and Culture. According to the framework for K-12 Science Education all students have sufficient science, technology and engineering knowledge to effectively engage themselves in public discussions, develop critical thinking, deal with every day related issues and information and choose careers in science, engineering and technology (National Research Council of the National Academies, 2012). In 2014 a research agenda was developed with the aim of determining the approaches and conditions most likely to lead to positive outcomes of integrated STEM education at the K–12 level in the United States of America (see The National Academies of Sciences, Engineering Medicine, 2014). It should be mentioned that through STEM education students learn to be capable to adapt and respond in a world of complexity and contradiction (UNESCO, 2015). In STEM education, the educational process focusses on inquiry-based learning and students acquire knowledge by participating in STEM activities.

STEM education focuses on developing the 21st century skills such as critical thinking, interdisciplinary problem solving, creativity, innovation and team work. Students through STEM education develop high-level skills, work and learn together in an inquiry-based approach, familiarize themselves in finding interdisciplinary solutions to the problems and build and share knowledge. In the United States of America, in grades K-12, technology and engineering have already been integrated in science and mathematics teaching and learning. In this way students become more prepared for dealing and finding solutions in complex problems. However, STEM education is not sufficiently introduced in the curriculums of European educational systems and this is the reason why many European Projects are active at the time being (Brzozowy et al., 2017).

In Europe STEAM education is much less popular than STEM education. It is noted that many European projects are about to be funded so as STEAM education be promoted in the educational systems of European countries.

1.1. STEAM education: Beneficial approach or not?

During the last decades, many new educational approaches have been applied throughout Europe. Nowadays, educational approaches based on the STEM education become more and more popular. The main reason is that as the needs of the labor market constantly change students have to become more creative during their school lives so as to become adaptive and competitive in their work-life.

It should be noted that project-based learning is a powerful teaching method that benefits students, teachers and school community (Larmer et al., 2015). It motivates students to come across with unresolved problems of their daily life; helps students meet standards and do well on tests; allows teachers to teach in a freer and satisfying way. Thus, students consider their school as an organization that is in contact with the local community and helps them to deal with problems appearing in every-day life.

When arts and culture are integrated in science issues, new educational environments open up and students improve even more skills (Land, 2013). In this way they may become even more creative because they have to combine data from five different fields (Science, Technology, Engineering, Arts and Mathematics) in order to make decisions and/or to draw conclusions. Moreover, the competitive European labor market needs forces students to emphasize in problem solving using their imagination and creativity and perceive that STEAM disciplines are relevant and useful to their lives.

Students can participate in STEAM activities both inside and outside classroom. Students outside the classroom are exposed to STEAM connections in science centers and museums. To this point difficulties arise concerning school organization, teacher's preparation in teaching in an integrated STEAM way and students' assessment because activities outside the classroom need to be very well planned and organized. The latter is very crucial because through it the school as an educational organization and teachers' ability in teaching are evaluated. So, it should be continuously determined what students have learnt and what additional knowledge they have obtained.

There are still many barriers as far as gender equality issues and gender bias in education and job careers are concerned. As a result, a lower retention of STEM career interest among girls is indicated (Hill et al., 2010). Moreover, girls who are more familiar with science activities are interested in following STEM careers where they are significantly underrepresented (Sadler et al., 2012). In other words, girls develop their appreciation for STEAM education and are more likely to pursue careers in science and technology.

1.2. Astronomy and STEAM education

Astronomy is all around us: the sunset, the sunrise, the faces of the Moon, the stars in the night sky. Astronomical discoveries have always captured the imagination of scientists but also of students as well.

The contribution of astronomy in science education is significant because scientific concepts are easily conveyed to students and thus astronomy may stimulate students' interest in all of science (National Research Council, 2011).

Students' imagination is excited by astronomy. Students make stories in their attempt to learn about the universe and are interested in visiting planetariums and observatories. Students with struggling readers' achievement could also benefit when attending a Technology-Enhanced STEM Astronomy Curriculum (Marino et al., 2010).

Astronomy, as the epitome of interdisciplinarity (Beet, 2015; Keeley & Sneider, 2012) and Space Science are at the forefront of science and technology. Students through astronomical activities relate to astronomy and learn through an integrated STEM approach to handle complexity, develop holistic thinking, communicate effectively, develop project management skills, professional and technical excellence.

Astronomy as a discipline interacts with physics, biological and computational sciences. Astronomy uses modern theoretical physics in formulating explanatory theories about the universe, engineering for planning space missions and constructing new instruments and biology for answering fundamental questions about life in Earth-size planets (for more see https://exoplanets.nasa.gov/). Moreover, astronomical knowledge and research contribute to the design of new technological products with social implications and economic benefits.

Students' involvement in STEAM activities requires teachers' training. The training of teachers in scientific subjects (not just in astronomy), has been acknowledged as of vital importance since 2008 (Bode, 2010). School across Europe need teachers properly trained so as to make students enthusiastic about careers in science by studying astronomy (ASTRONET, 2008).

Culture and society are an integrated part of science and technology. This view is corroborated by the Astronomical Union's (IAU) strategic plan for 2010–2020 which is focusing on three main areas: technology and skills (optics, computers, electronics, space) science and research (mathematics, biology, chemistry, physics), culture and society (inspiration, perspective immensity of the universe, history, anthropology). Thus, astronomy should be taught undoubtfully with STEAM activities, and moreover with the next level of STEMAC that STEM includes arts and cultural heritage (Liritzis, 2018).

1.3. *Revisiting the values of the Arts and Culture in Science Education*

In antiquity, significant advances in astronomy and mathematics were made thanks to the use of arts and culture as a means for the interpretation of the motions of the heavenly bodies. Arts and culture are used for subjective interpretations of the world; astronomy and mathematics or sciences are used for objective interpretations of the world (Sousa & Pilecki, 2013).

The arts cultivate the imagination while sciences are based on logical sequences. Arts are complementary to sciences because they are based on human experience. Therefore, their role in understanding the sciences is crucial. Worth mentioning is that the procedure of scientific theories and the results of the experiments in laboratories are visualized the arts; data analyses of the experiments are also depicted as graphs.

STEM scientists have already studied the scientific issues in an interdisciplinary approach that may integrate arts and culture. This approach is very productive for secondary and high school students and teachers should be encouraged to implement it in their teaching (Kim et al., 2013). This is an innovative way for teachers to make science education attractive to young people and at the same time to promote collaboration among students. Teaching astronomical issues through STEAM activities in an interdisciplinary approach is equal to teaching mathematics, physics, geometry of the sky, anthropometry, anthropology, anthropology, mythology, history of astronomy, religion issues, art, music etc. at the same time (Fucili, 2005; Liritzis, 2018).

STEAM education has already been endorsed in the national curriculum documents of some countries, such as those of Korean educational system (Jho et al., 2016). Here, the main difficulty that arises is the lack of collaboration and communication skills among the teachers of the different disciplines. STEAM activities are difficult to be implemented in schools as they demand the collaboration of teachers from different subjects. Moreover, another difficulty is teachers' views. Some of them have objective, logical and analytical thought while others are subjective, intuitive and sensual. However, teachers' training in STEAM activities should overcome these difficulties as arts make teaching more interesting for STEM teachers (Sousa & Pilecki, 2013).

2. THE HOROLOGION OF ANDRONIKOS KYRRHESTES AS A STEAM EDUCATIONAL EXAMPLE

Greece has an abundance of archeological treasures. Some of them have been characterized as Monuments of Cultural Heritage by UNESCO. However, two of them have only been characterized by UNESCO as monuments of astronomical significance: the "Pnyx" (Wright & Ruggles, 2011-2012) and the "Horologion of Andronikos Kyrrhestes"

(Liritzis & Panou, 2017-2018). These are both of archaeological interest and astronomical interest and could be efficiently used to teaching astronomy through STEAM activities.

The Horologion of Andronikos Kyrrhestes is an archeological monument close to the Roman Agora of Athens, Greece. It is a typical example of a Greek heritage monument that could be used in the education process in teaching astronomy, mathematics, engineering, technology, culture, arts etc.

2.1. Horologion of Andronikos Kyrrhestes- UNESCO Monument of Cultural Heritage

The Horologion of Andronikos Kyrrhestes (Fig. 1) was built in 100 B.C. by the great Greek astronomer, engineer and architect Andronikos Kyrrhestes who was also its sponsor (Noble & Price, 1968; Wycherley, 1978; Kienast, 2013). It is mostly known as "The Tower of Winds" or "Aerides" (which means "Winds" in Greek). The building made of Pentelic marble is an architectural masterpiece of the late Hellenistic period. The main building has octagonal structure and a cylindrical annex is attached to its south side. In the northeast and northwest side of the main building there are two large openings serving as entrances. The entrances denote the north orientation and the annex the south. Thus, the monument is constructed in the north-south orientation enhancing its astronomical importance and use.

Figure 1. Northern view of the Horologion of Andronikos Kyrrhestes

Mounted on the external surface of the octagonal building, are the personalized figures of eight wind deities: Boreas (north wind), Notus (south wind), Apeliotes (east wind), Zephyrus (west wind), Kaikias (northeast wind), Skiron (northwest wind), Eurus (southeast wind), Lips (southwest wind) which indicates the use of the monument as a weather forecasting station (Vitruvius, 1914; Varro, 1912). Below each wind deity a vertical sundial is engraved. In total, there are engraved eight sundials which were operated in sunny days as clocks or/and calendars. Sundials in antiquity were used as astronomical instruments for measuring the time of the day and determining the season of the year. Another sundial was engraved on the external surface of the cylindrical annex. Contrary to the vertical ones this sundial is not preserved.

Inside the building there are traces which enhance its astronomical use. On the surface of the internal walls there are drawings; on the floor, there are curving grooves, straight channels and round-shape beddings; the roof is divided in 24 marble plates of similar dimensions and bear traces of dark blue color pigments. All these facts reveal the use of the tower in ancient times as a hydraulic mechanism which was operated with gears and water, a mechanism similar to a planetarium. However, the Tower of Winds served also for social and commercial purposes; it was a meeting point for ancient Greeks.

The Horologion of Andronikos Kyrrhestes is a monument of astronomical heritage because it is related to social uses of astronomy in ancient Athens and in Ancient Greece in general. The Tower of Athens has recently been recorded in UNESCO portal "Portal to the Heritage of Astronomy" and is presented in detail with great emphasis to its astronomical and social importance (Liritzis & Panou, 2017-2018). It is the only monument preserved since the Hellenistic period that is related to astronomical observations, cultural activities and to the application of astronomical techniques and technology to other sciences, such as mathematics and arts.

2.2. The monument and its "STEAM components"

Astronomical observations for determining time (hour and seasons) and for predicting various phenomena such as the eclipses of the Sun and the Moon lead to astronomical building constructions, e.g. the "Horologion of Andronikos Kyrrhestes". Here a question arises: What are the knowledge areas for constructing such a great building? Some such areas are: astronomy, mathematics, technology, engineering, architecture, sculpture (Fig. 2). Here, the component of science, such as mathematics and engineering, is represented by astronomy and the component of arts by architecture and sculpture.

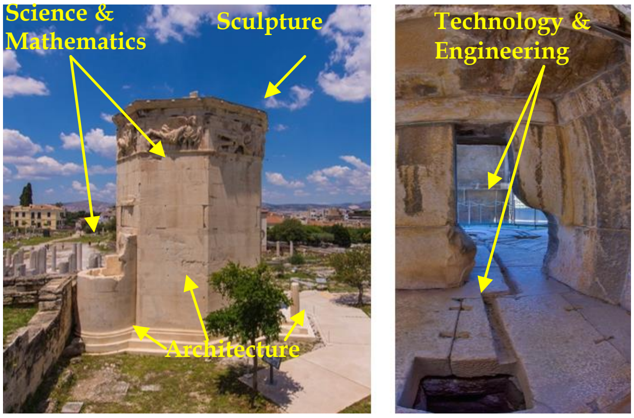

Figure 2. The "STEAM components" of the Tower of Winds. Views of the exterior (left) and interior (right) of the monument from the East and South respectively. The arrows show which STEAM component was used for the construction of every part of the building.
Source:
https://www3.astronomicalheritage.net/index.php/show-entity?identity=90&idsubentity=1

Astronomical knowledge was necessary for the construction of the "Tower of Winds". The observation of the motion of the Sun in the sky and its trajectory led to the invention and construction of astronomical instruments such as sundials in various types, shapes and dimensions. As it was mentioned above, the monument had eight vertical sundials in the upper part of the main building and another one on the external surface of the attached cylindrical annex. All sundials were constructed for measuring the daily hours from sunrise to sunset and determining seasons throughout the year. This indicates the vital importance of measuring time in antiquity and its crucial role in everyday human's life. Moreover, in the central part of the building a planetarium was constructed for many astronomical purposes such as for measuring time during cloudy days and determining the planets heavenly motion.

Mathematics is the base for the development of astronomy. Therefore, it is not accidental that the sundials of the monument are constructed with great mathematical accuracy. From in situ measurements on the sundials' surface (Panou, 2016) it is verified that engraved sundials are mathematically accurate constructions.

Moreover, mathematics gave a boost development of architecture and sculpture in antiquity. The "Tower of Winds", as a building, is an architectural masterpiece that was constructed with great accuracy due to its geometrically symmetric construction. Knowledge of sculpture was very helpful in the decoration of the monument and especially in the construction of the eight personalized wind deity figures, in the engraving of the lines and curves on the surface of the sundials and in the internal decoration of the building.

Finally, technology and engineering were vital for the use and function of the monument. The planetarium operated with gears and water (straight channels on the floor carry water to the inner part of the building) and was constructed thanks to ancient technological and engineering knowledge. If there was no planetarium, the monument would not have been of any astronomical importance.

2.3. *The monument as a STEAM educational example*

The "Horologion of Andronikos Kyrrhestes" may serve as a STEAM educational example for teaching sciences, arts and culture as the knowledge needed for monument's construction and its conservation comes both from the positive and the human sciences.

The monument reflects the complementary use of science and arts during the time and represents the holistic approach of the philosophical thinking of the era. The comparative advantage of the use of this monument in teaching is that all students may involve themselves in activities no matter what skills they have already developed or what subjects they like the most. The STEAM approach may be reinforced by a Virtual Reality Modelling Language VRML exploration of the monument (e.g. Eggarxou & Psycharis, 2007).

Moreover, students may involve themselves in activities they are not familiar with and be accustomed with the interdisciplinary way of thinking. In our view the interdisciplinary approach is the way we may successfully deal with the problems of our everyday life.

2.4. *Greek teachers' opinions of STEAM education*

We selected a purposive sample (Patton, 1990) of teachers who teach different subjects in public schools of secondary education in Greece.

Semi structured interviews were designed for recording teachers' opinions about STEAM education using as example the "Horologion of Andronikos Kyrrhestes" monument.

3. TEACHING USING THE "HOROLOGION OF ANDRONIKOS KYRRHESTES"- RESULTS

The analysis of semi structured interviews showed that most of the teachers had never implemented STEM activities inside or outside the classroom through arts. However, two out of three teachers were keen on using the "Horologion of Andronikos Kyrrhestes" as an educational example. Female teachers who teach positive sciences are more willing to use this or other monuments of astronomical heritage in a teaching scenario. On the contrary, male teachers were more hesitant. A large percentage of female teachers of human sciences held the view that STEM knowledge may be more easily obtained by students when arts and culture are involved in the teaching process while most male teachers supported an integrated STEM approach rather than a STEAM one. In addition, a percentage of over 90% of the teachers stated that they would obtain STEAM educational training to become more familiarized with arts in STEM activities.

It should be mentioned that our research showed that teachers' responses are a function of gender; female teachers were more open in using arts in science teaching sciences than male ones. Thus, we hold the view that further research should be conducted in this direction, namely in what was is gender related to STEAM education.

4. CONCLUSIONS

Science and the arts work together to enhance creativity and innovation. In Greece, teachers are not familiarized with teaching astronomy, as astronomy is not a separate subject in secondary education curriculum. The curriculum of arts and culture subjects is not connected to STEM activities. However, our research showed that Greek teachers are willing to teach the subject they are specialized in by using STEAM activities involving astronomical monuments of cultural heritage. Of course, this presupposes that teachers should undergo training; Nonetheless, our research showed that teachers are willing to be trained in this direction.

Further research should be carried out and Greek curricula of secondary education should be reformed according to the STEAM educational so as creativity and innovation be promoted. The curriculum structure of every subject should be developed in a way so as the interdisciplinary problem-based structure should be at the forefront. Thus, Greek students will be more capable in solving complex problems by engaging themselves in team-based multidisciplinary problem solving and thus become more competitive in the future European labor market.

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