Three Dimensional Printing Technology in Science and Engineering Education. A Best-practice: Study, Design and 3D Print an Operational Model of a 2000 Year-old Computer

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Abstract

3D printing technology is an established industrial practice for rapid prototyping and manufacturing across a range of products, components and commercial sectors and at the same time possesses great potential for every-day life applications to be envisioned, invented, explored and developed by the coming generations of scientists and engineers. A 3D printer installed in a school setting and complemented by well-designed educational activities can: stimulate the interest and curiosity of students; engage and motivate them into studying science, technology, engineering and mathematics (STEM) subjects, that they may choose or consider as career options; give the opportunity to teachers to achieve content and concept learning in an innovative way. In this paper we present an interdisciplinary science course that was developed for high school students and was implemented in an actual science classroom. The objectives of the course were both to spark the interest and creativity of students and teach them certain curriculum units the content knowledge of which is reached or utilized in an unconventional way. Students are gradually introduced into the 3D printing technology, its application and potential and are assigned a challenging collaborative project in which they have to study, analyze, design and build, using the 3D printer of their school, an operational model of a renown ancient artefact, the so-called Antikythera Mechanism. The mechanism is a 2000 year-old computer and is internationally known as an artefact of unprecedented human ingenuity and scientific, historic and symbolic value. The course involves the teaching of STEM curriculum domains of physics, astronomy, mathematics/geometry, informatics and technology related content and also non-STEM subjects like history and Greek language, both ancient and modern. We give an overview of the course, discuss its various phases and highlight its outcomes.

1. Introduction

3D printing technology is an established industrial practice for rapid prototyping and manufacturing across a range of products, components and commercial sectors [1]. It also possesses great potential for every-day life applications to be invented, explored and developed by the coming generations of scientists and engineers [2]. A 3D printer installed in a school setting and complemented by well-designed educational activities can: stimulate the interest and curiosity of students; engage and motivate them into studying science, technology, engineering and mathematics (STEM) subjects, that they may choose or consider as career options; help them to achieve content and concept learning in an innovative way [3,4,5,6]. We developed an interdisciplinary science course for high school students which was implemented in the form of optional educational activity during the school year. The objectives of the course were both to spark the interest and creativity of students and teach them certain curriculum units the content knowledge of which is reached or utilized in an out-of-the-ordinary way. The core of the course is a formidable challenge addressed to students, namely to study, understand, design and build a complex scientific instrument, known as the Antikythera Mechanism, using the 3D printer of their school. In this way a high-tech artefact of the ancient world is linked to a cutting edge technology of the present era, a symbolic link that engages the students that already have strong STEM related interests, but also inspires and motivates those less-interested to explore and develop them. In the following we briefly present the Antikythera Mechanism and then give an overview of the course where we describe its main phases, highlighting also the links to the school curriculum. The paper concludes with a section where the main expected learning outcomes are discussed. Similar educational activities using 3D printing as teaching tool that are under development and will be implemented in the next school year are also reported.

2. The Antikythera Mechanism

The Antikythera Mechanism (Fig.1) is an extraordinary mechanical device with gears, display indices and dials, constructed in Ancient Greece around the end of the second century B.C. It was found accidentally in 1901 by sponge divers at the bottom of the sea in a shipwreck near the island of Antikythera in Greece. Its complexity astonished, and continues to amaze, the international community of experts and historians on the ancient world as it is technically more complex than any known device for at least a millennium afterwards. Research over the last decades gradually revealed its secrets and decoded its operation and specific functions [7,8]. It is now known that it calculated and displayed astronomical information, particularly cycles such as the phases of the moon, the motions of the sun and the moon across the zodiac along with luni-solar calendars used in ancient times. The mechanism also predicted lunar and solar eclipses and displayed information on periodic events of social significance in the ancient world such as the Olympiad and other important Panhellenic Games. In a nutshell, the device is a mechanical realization of the scientific knowledge and understanding of the cosmos of that epoch. It is internationally known as an artefact of unprecedented human ingenuity and scientific, historic and symbolic value. Since its discovery it has inspired scientists and engineers with its degree of technical and scientific sophistication. Similarly it can stimulate, inspire and engage young students through interdisciplinary educational activities that naturally combine science, technology, engineering and mathematics subjects.

Fig.1. The main fragments of the Antikythera Mechanism as displayed at the National Archaeological Museum of Athens, Greece.

3. Description of the course

The full course consists of 5 phases, discussed below, that total 20 sessions, about 2 hours long each conducted in a weekly basis. It was proposed and started in the school year of 2014-2015 with an announcement/invitation poster to high school students (aged 15-18 years old) to join. Participation is optional and there are no prerequisites or selection in terms of knowledge or skills. The course of this year is offered as an extra-curriculum activity and is taking place outside the regular school time schedule. All the activities and students' work are during the weekly scheduled 2-hour slots and there are no homework or other assignments to be carried out. The actual poster/leaflet posted at the announcement boards of the school is shown in Fig.2, its main message line reads "study, analyse, design and build/3d print an operational model of the Antikythera Mechanism". The leaflet includes also a short description that states that the course is a challenging collaborative project that involves various subject domains that include, physics, astronomy, maths, geometry, informatics, engineering/technology and also history and ancient Greek language! The main challenge is communicated from the start, i.e. the final goal is to build an operational device, and not a static model, that functions like the real instrument. The course quickly attracted the interest of students and a first working group was formed (Fig.2). About two thirds of the participant students have proven STEM related interests and skills, overall half of the group are female students.

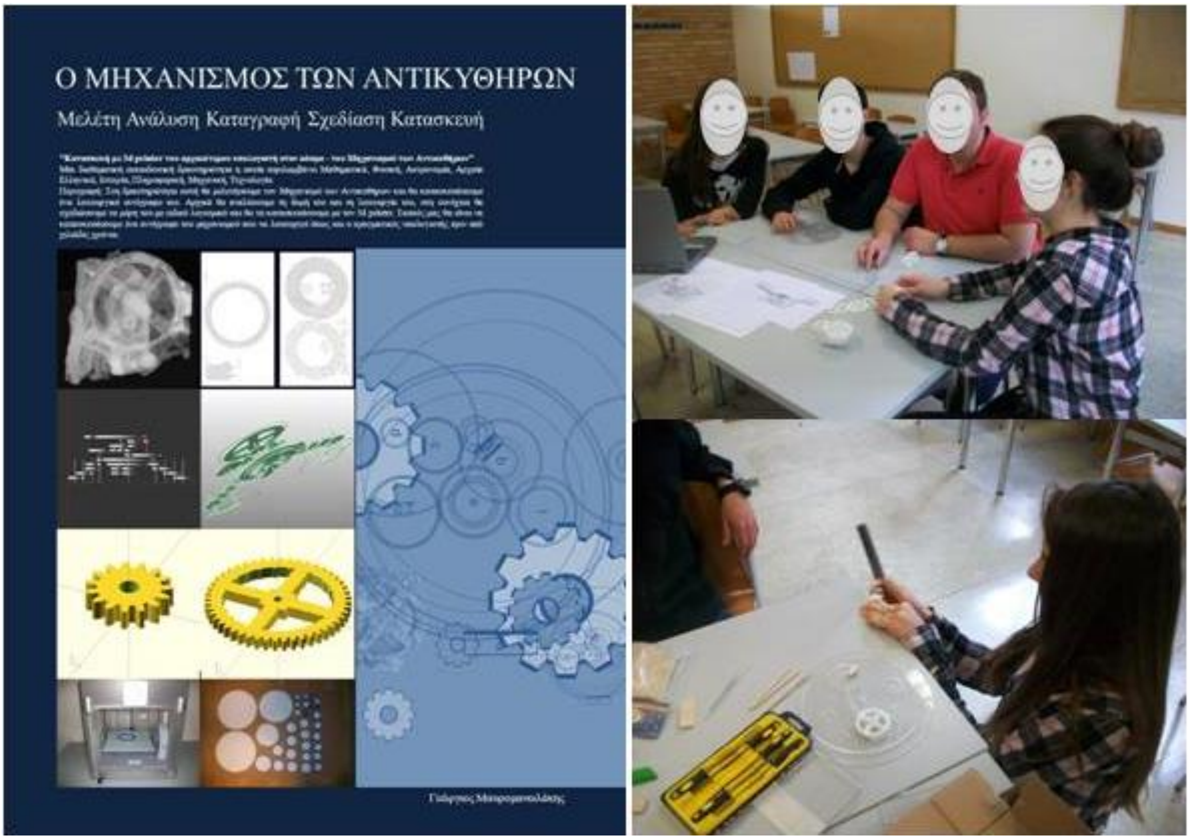

Fig.2. Poster/leaflet about the course distributed and posted at the announcement boards of the school. Its main message line reads "study, analyse, design and build/3d print an operational model of the Antikythera Mechanism". The photos to the right show students working on the assembly of the mechanism.

3.1 Phase I – Study and Analysis

In this phase students are given various introductory and informative materials, print and online resources about the mechanism that they have to study in order to gradually understand its components and operation. With the help of the supervising tutors they have as main objective to identify the main elements of the mechanism, i.e. its gears and their relationships. To accomplish this they use free 3D visualization tools of engineering drawings and gear simulation software. They practice their knowledge on maths and geometry related subjects to derive main geometrical parameters and relationships. In order to fully understand how a mechanism of gears works they further develop concept and content knowledge of physics curriculum topics like forces, torque, equilibrium, circular motion, through experimentation and inquiry-based simulation resources [9] and well-known applets [10]. Some session time of this phase is devoted to discuss topics from the astronomy curriculum e.g. planets, solar system, stars, etc. This phase ends with a documentary movie about the discovery and investigation of the Antikythera Mechanism along with its historic and scientific implications.

3.2 Phase II – Design

During this phase students are learning to use computer-aided-design software to design themselves the components of the mechanism which they will then build with the 3D printer. Free, open-source software is chosen for this purpose (available from www.openscad.org). It offers an integrated user interface for coding, rendering and visualizing in 2D and 3D. Furthermore its basic instructions and commands that students have to use resemble the syntax of a high level programming language, i.e. C++. In this way students practice and further develop their knowledge on informatics related curriculum topics, like code development with variables, functions, libraries, conditional and iteration statements etc. As students are split to work in groups they have to learn to share source code, specifications and design parameters and cross-check each other's work. Most students are very eager to quickly see their designed objects being created by the 3D printer. Thus it is recommended that they proceed to 3D print preliminary draft designs, in order to comprehend the transition from the virtual to the real world and have first-hand experience what rapid prototyping means, which are the implications of 3D printing in industrial and commercial applications. During this and the following phases, and depending on progress, there are sessions when a historian/philologist is invited to present to students the social, cultural and political status of the 2nd century B.C. when the Antikythera Mechanism was designed and constructed. With his/her help students also process high resolution images and scans of fragments with inscriptions in ancient Greek language. They decipher words and phrases which survived in their present day native language.

3.3 Phase III – 3D Printing

This phase may run in parallel with the design phase. In this phase students "produce" using the 3D printer of the school what they have designed. They may need to go through tests and changes to refine and optimise their designs before they reach final good quality results. As a consequence they experience and understand common engineering processes and what production development cycle means. During this phase they may also investigate what other methods of manufacturing and production they may have used, which are their advantages/disadvantages and associated costs. With the help of the supervising tutors they wonder how a mechanism of such complexity could have been designed and built two decades ago, two hundred years ago, or two thousand years ago. They discuss and reflect on subjects like scientific and technological developments and breakthroughs, impact of science and technology on society, examples and projections from the past to the future, etc.

3.4 Phase IV – Assembly

In this phase students proceed to the final assembly of the mechanism. They celebrate the moment where all components are put together and the whole construction is set in motion. They discuss and reflect on all the steps, problems and challenges they have been through and how they resolve them and overcome difficulties. This phase ends with a visit to the National Archaeological Museum of Athens where fragments of the Antikythera Mechanism are displayed (Fig.1).

3.5 Phase V – Presentation

During this phase students work on making a comprehensive presentation of the project and their experience in order to share it with the school community and the general public. They use the material they have collected and recorded during the previous phases such as photos, videos, drawings etc. They have to compile all the information in a concise report that will be shown in various formats e.g. documentary video, poster or lecture, at science and technology fairs organized by schools and the educational community or other thematic events.

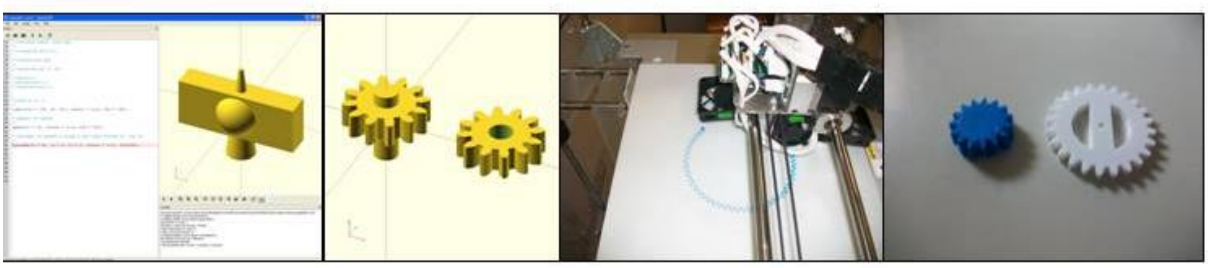

Fig.3. Highlight pictures/photos from the various phases of the course, (from left to right) the openscad user interface, designs of gears, the 3D printer in operation, examples of 3D print-outs.

4. Learning outcomes

In this course high school students are gradually introduced into the 3D printing technology, its applications and potential and are engaged in a challenging collaborative project in which they have to study, analyse, design and build, using the 3D printer of their school, an operational model of a renown ancient artefact, the Antikythera Mechanism. To accomplish this they acquire solid knowledge and understanding by inquiry and practice in a variety of curriculum subjects of physics, astronomy, maths, geometry, informatics, engineering/technology and also history and ancient Greek language. During their work they improve their social and verbal skills (collaboration, communication, presentation, project planning and management), develop key competencies (creative learning, innovative thinking, problem solving, cross-disciplinary thinking) and digital literature. They perform tasks like real scientists, researchers and engineers do for their everyday job, and learn and develop similar work practices and attitudes.

5. Under-development science courses with 3D printer

Similar interdisciplinary educational activities that use 3D printing as a central teaching tool are under development and will be implemented from the coming school year for junior high-school and high-school students, aged 12-15 and 15-18 years old respectively. One activity is about creativity, geometry and maths and its main goal is to capitalize on the direct visualization and instant production of tangible objects 3D printing offers [5,6]. The activity is focusing on the visualization of geometrical patterns, shapes and solids. It also complements the teaching of more abstract concepts, from set theory and mathematical logic, the understanding of which can be greatly facilitated with tangible 3D objects which are studied, designed and produced by the students themselves. Another activity under development is on geography, geology and environmental sciences. A variety of high resolution satellite survey images and data are now publicly available online and can be downloaded freely for educational purposes. Through specialized processing software they can be utilized to create three dimensional maps, which can be 3D printed, of countries and areas of interest that the teachers and their students choose to focus on.

6. Summary

We presented an interdisciplinary science course that was developed for high school students and is implemented in an actual science classroom setting. The objectives of the course were both to spark the interest and creativity of students and teach them certain curriculum units the content knowledge of which is reached or utilized in an out-of-the-ordinary way. Students are gradually introduced into the 3D printing technology, its application and potential and are engaged in a challenging collaborative project in which they have to study, analyze, design and build, using the 3D printer of their school, an operational model of a renown ancient artefact, the Antikythera Mechanism. The course greatly facilitates the teaching of curriculum domains of physics, astronomy, mathematics/geometry, informatics and technology related content and also non-STEM subjects like history and Greek language. We gave an overview of the course, discussing its various phases and highlighting its main outcomes.

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