Experimenting with the shape of the Earth's relief through surface runoff tables: A P2P STEM didactic scenario approach for Makerspaces

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Abstract

It is very important that students of today, the citizens of tomorrow, comprehend natural disasters, such as floods, forest fires, corrosions and human interventions, as factors that shape the terrain of the area in which they live in. This necessity is because natural characteristics of basin runoff, affect the microclimate of the area, the fauna and flora and in general the area's evolution. In this paper, we design and propose a STEM – compliant scenario to study and experiment with the shape of the Earth's relief, using a runoff table artefact. Students simulate scenarios of surface runoff by changing the angle and water flow. The proposed STEM approach involve students with the design process to solve a real problem, the programming of the artefact and the interpretation of the collected data. The scenario focuses on collaborative work – places such as makerspaces, in which students design, explore and construct artefacts, based on open software and hardware tools.

Key words: Surface Runoff table, Physical Computing, STEM, Geomorphology, LabVIEW, P2P, Makerspace

Introduction

STEM education, is a scientific and research area which is not yet fully defined. This concerns both the research community and education policy makers in many countries. The demarcation point as to which approach is STEM and which is not, relates to the teaching models used, to the assessment tools, to the curriculum involved, to the form of education and to the concepts involved (Psycharis, 2020; Tillinghast, et al., 2020). STEM is much more than an acronym; it is a philosophy and an innovative way of approaching the educational process. A STEM educational approach presupposes not only the simultaneous involvement of four disciplines (i.e. science, technology, engineering and mathematics), but also encompasses the direct involvement of students in all its stages. Therefore, a STEM approach supports the understanding of engineering and construction activities, along with improving students' engagement with technologies in an interdisciplinary way (Bybee, 2010).

A STEM oriented curriculum, directly engages students with real – life problems. Teachers often deal with the problems in a holistic way and do not investigate the solution as separate sub – problems. The STEM approach allows a teacher to investigate concepts from each discipline and to point out how separate scientific fields are all necessary to solve a problem. In that way, students can design and work out their modular way of thinking, test their solution on experimental data, and reshape their thoughts about their prototype artifact. This process can be implemented using either physical computing (i.e. Arduino construction), or simple computer – free, unplugged STEM approach (Psycharis, et al., 2020). The STEM approach is enhanced through peer to P2P (peer to peer) learning, according to which students' are involved in a work process in which "they learn from their classmates". This process is mutually beneficial and involve the sharing of knowledge, ideas, experiences, of all participants in a group. Peer STEM education is also a way for a student to move from independent to interdependent and mutual learning environment (Kennedy et. al, 2014).

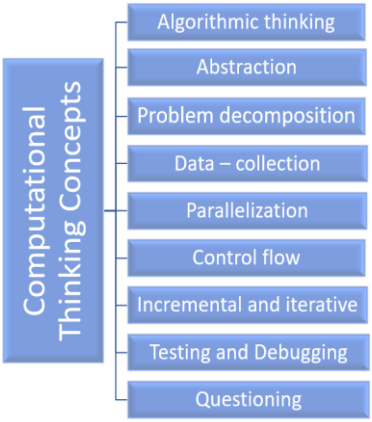
The primary goal of any STEM program should be the students' development of a demonstrative way of thinking in mathematics, in design thinking in engineering, in scientific research an in computational thinking in technology, which while being separate and independent approaches, are somehow interconnected, through problem solving and experimental processes (Glancy & Moore, 2013). To this end, STEM activities, apart from being enjoyable, allow students to think, to seek for solutions by developing their imagination and creative thinking, and to collaborate and communication among groups. A prerequisite is that these activities should constitute the appropriate conceptual framework (Bottia, et al., 2018; Patrinopoulos & Iatrou, 2019).

Computational Thinking and STEM Pedagory

Almost after three decades, information and communication technologies (ICT) have dominated in the education field, initially as supportive tools for other courses of autonomous cognitive objects, but gradually have evolved and expanded their influence, through the process of computational thinking. We could define "computational thinking" as a mental process involved in shaping a problem and expressing its solutions in such a way that a dipole "computer – human" can handle it effectively by collaboration (Wing J., 2014).

As it is widely accepted, computational thinking is a kind of analytical thinking. It embraces the mathematical way of thinking to approach the solution to a problem. Additionally, it shares encompass with the engineering way of thinking, the ways with which we could approach the design and evaluation large and complex systems that operate within the constraints of the real world. Finally, it supports the scientific ways of thinking with which we approach the understanding of computational processes, intelligence, cognition, human wit and behavior (Wing, 2008). The following figure, shows the computational thinking dimensions, according to research studies of (Weese & Feldhausen, 2017)

The introduction of computational science in education is now considered, as an approach that should be taken into account in STEM educational planning, due to its positive effect. As reported (Wing, 2014) in 2012 the British Royal Society in its report on education status, states that the "computational thinking" offers alternative ways of understanding physical and technological systems through the multileveled impact on human through processes and proposes that each child should be given the opportunity to experience this approach inside school. This report has shaped the UK National curricula as presented in 2013, and predicts that students should be taught computational science concepts, depending on their age level. In shape 1 we present the computational thinking concepts, as defined by Weese (Weese & Feldhausen, 2017), which highlight the basic STEM pillars any STEM didactic approach should rely on.



Shape 1. Computational Thinking Concepts according to Weese & Feldhausen,

Computational content STEAM pedagogy seems to be effective in teaching and learning, as well as on students' capacity to implement this in a form of didactic scenario. Students can use this methodology (i.e. epistemic approach) to develop inquiry based scenarios, to collect and analyze data and to decompose a given real – life problem. They are also engaged in the abstraction process and in developing code using optical and text – based programming, as well as physical computing. In addition, they can design and make artifacts based on engineering, engage in the creation of prototype and understand that prototype should be tested according to the outcomes of the collected data from their model (Psycharis, S. 2018). This article is based on the conceptual framework of computational STEAM pedagogy, as students engage themselves with experiment and testing of their model, which estimates the Earth's relief, through a series of runoff table artifact, as presented below.

STEAM and Geoscience

It is important that students, the citizens of tomorrow, understand natural disasters, such as floods, forest fires and human intervention, are factors that shape the terrain of the area in which they live in. This necessity is because natural characteristics of basin runoff, affect the microclimate of the area, the fauna and flora, and in general the area's evolution. STEM didactic scenarios focusing on Geoscience for students, awake their consciousness regarding the environment. Focusing on solving authentic problems, students, face problems related to geological mapping, other basic geological concepts, and geological historical events of each area, hydrology and environmental geology. In these projects, students are often asked to combine engineering techniques, to create and artifact or model, mathematics, to collect and analyze their data and computer science, to further understand geo-mappings through simulation models, or GIS tools for Geology.

These projects, are usually implemented within the natural environment and not within an ordinary schoolroom. In this way, students are given the opportunity to gain experimental experiences, to participate in STEAM activities through excursions, camping, workshops and other activities that enhance their sense of participation and serve to build students' confidence level of success in STEM. Additionally, they increase their interest in Geology and Geoscience, and pursue careers related to Geosciences (Llanes, 2016; Musavi, et al., 2018;

Janowicz, 2020; Tillinghast, et al., 2020). Our presented scenario's construct phases engage computational thinking pillars and makerspaces philosophy, which engages students with engineering principles, construction, data collection and analysis, testing and debugging.

Therefore, in this paper, we propose a P2P STEM - related Geoscience scenario, focusing on constructing runoff table for studying and experimenting with the Earth's surface relief. The scenario triggers students to experiment with soil erosion process, using a runoff table artifact, as constructed with recycled materials and physical computing sensors. Following, we given the reader all necessary scientific information regarding runoff tables and afterwards we present our STEM scenario.

Surface runoff table Background Concepts

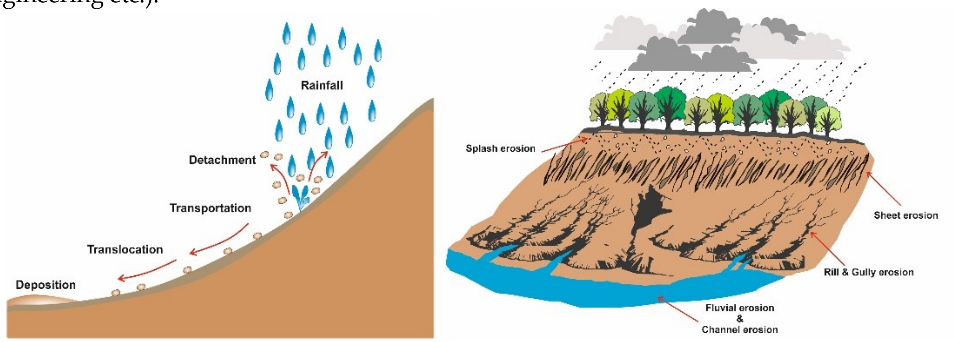
The perpetual movement of water between the atmosphere, hydrosphere, lithosphere and biosphere, has an impact on the shaping of the Earth's relief. A portion of the water that falls over the land flows superficially, a process referred to as surface runoff. The main exogenous process has led to the shaping of the Earth's relief, though weathering and erosion. Weathering refers to the removal of rock and soil material and the production of sediments. The rock disintegration is due to both physical and chemical processes, as well as biogenic ones (e.g. Charlton, 2008; Huggett, 2011; Theodorikas, 2017; Evelpidou, 2018). The produced sediments are removed from their in situ position through the water, gravity or wind and get transported downstream. The distance of their transportation depends on several factors, such as their size and the power of the force that leads to their movement (for instance, the velocity of the flowing water). When it comes to size, fine sediments are generally transported at greater distances than coarse ones. The power of the transporting force determines the distance at which a grain of a given diameter can be transported and mainly depends on the gradient of the slope (e.g. Charlton, 2008; Huggett, 2011). Coarse sediments are transported through traction; medium-sized sediments are transported through saltation and finer ones through suspension (e.g. Evelpidou, 2018).

The total fluvial sediment load is grouped into two categories. The material that stems from the bed itself is referred to as bed material load, whereas the sediments that are produced through the erosion of the flood plain during high flow events is called wash load. The overall process of the sediment removal, transportation and disintegration often referred to as erosion. They form three zones, based on which one of them is dominant, namely the erosion zone, which is mainly found in the upper part of a drainage basin, the deposition zone, which usually occupies the lower part of the basin, and the intermediate transportation zone (e.g. Evelpidou, 2018).

When the power of the force decreases (for example when the gradient is reduced or due to obstacles in the channel bed), the transported sediments are deposited into the channel bed, in the sea or, during high flows, in the flood plain (e.g. Charlton, 2008). The factors that affect the extent to which erosion takes place are climatic (such as intensity, quantity and duration of the rain), physiogeographic (mainly the slope gradient, length and shape, as well as the drainage network characteristics), geological, pedagogical, vegetational and anthropogenic. The latter mainly refers to land cover and management. Channel bed interventions such as waste disposal increase the bed roughness and force water to overcome its natural bed and flood. Furthermore, agricultural regions are more prone to erosion than forest areas, whereas a conflagration or deforestation also increases an area's vulnerability.

The aforementioned processes gradually lead to the formation of river valleys. Initially, soil erosion is caused by the raindrops (splash erosion), resulting in the removal of soil particles, which are transported downstream. Water flows superficially, forming a thin layer (sheet flow), until the first rills are formed, i.e. lesser parallel channels that are subject to down cutting erosion. These rills are further incised and widened and are finally conjoined, forming one or more gullies. These gullies are incised, as well as widened, further and at the same time, backward erosion, i.e. prolongation of the channels upstream. In this way, valleys are formed (e.g. Charlton, 2008, Bendahmane et al., 2017). At high flows, water exceeds the channel bed boundaries and inundates the drainage basin. This process is referred to as a flood (e.g. IPCC, 2012). At the same time, it bears fine-grained load, which is deposited in the inundated areas when water retreats. In that way, a floodplain is formed. The magnitude of most floods does not suffice to provoke changes in the floodplain, save the part on each side of the channel. On the contrary, drastic changes are generated when mega-floods occur (e.g. Charlton, 2008; Huggett, 2011).

All the aforementioned processes take place perpetually and therefore, the Earth's relief is a dynamic system, meaning that it is constantly evolving and changing. The processes and the results of each of them, along with the results of human intervention is an important discussion in various courses and education levels. Especially in natural hazards, e.g. flash floods it is important to understand and be able to 'observe' the evolution of the phenomenon. It is worth mentioning that the changes of natural characteristics of the drainage basins and climate are playing a crucial role in the evolution of the area. For instance, a change in the rain intensity and/or duration can result in the rapid flooding of an area. Moreover, human interventions, such as channel beds occupation, constructions into the beds or floodplains, channel bed reshaping etc., can also affect the flood hazard. All these processes are hard to observe and comprehend in the field, not to mention in mere images and videos, unless very well understood. These processes are taught both in schools (in several Geography, Geology and Environment courses and as general knowledge) and in universities (mainly in nature science faculties and courses, such as Geology, Physical Geography, Climatology, Hydrology, Engineering etc.).



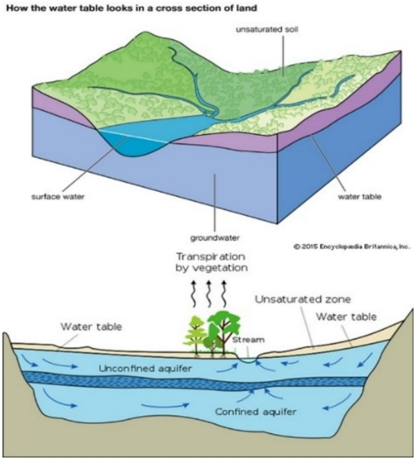
Shape 2. Splash erosion procedure and types of erosion

One way for both natural sciences/geosciences students and school pupils to observe such changes and understand the surface runoff processes is the usage of surface runoff tables that could simulate the surface runoff processes that take place in the nature. Besides aiding both students and pupils comprehend them, is worth mentioning that they are very easy to use for educational purposes in a laboratory or in the classroom. Therefore, they should be used in the class. This kind of tables may be filled with fine material (e.g. natural or artificial sand). Water could be dropped to the table and its movement causes the formation of a "river" channel. The relief this material forms, the gradient of the table, the quantity, the intensity and the duration of the 'rainfall', as well as the morphometric and physiographic features of the channel, can be changed at will. The user determines the velocity, quantity and duration of the added water, in order to simulate the rainfall characteristics. Water that flows into the channel reshapes the initially and artificially formed relief in the same way that it would in nature, but very quickly, allowing trainees to observe all the aforementioned processes and comprehend, for instance, the different zones (erosion, deposition and transportation zone) and processes, river meandering, delta formation etc. In this way, the initially formed channel is also changed. Shape 2 depicts the splash erosion and types of erosion (Evelpidou, 2020)

STEAM Geoscience Scenario

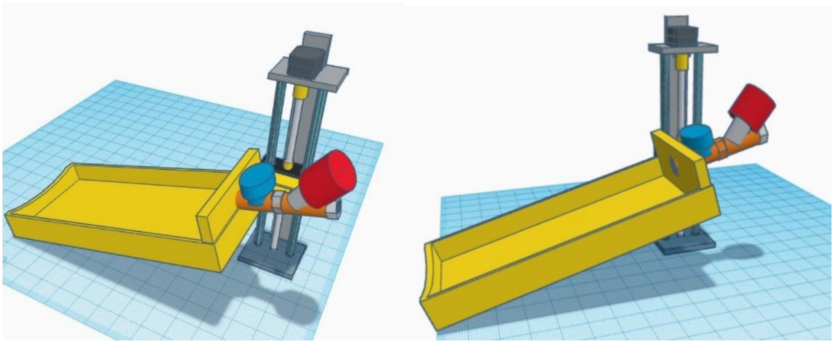
The design and usage of a surface runoff table can be used in an experiential STEM lesson, making the study of the Earth's relief and the contextual processes both easy to understand and entertaining. Students can have the ability to not only observe them, but also actively participate in the lesson (e.g. by determining the water and "relief" characteristics themselves). The surface runoff tables could simulate the surface runoff processes that take place in nature. Besides aiding both students and pupils to comprehend them, it is worth mentioning that they are very easy to apply for educational purposes in a laboratory or in the classroom. This kind of tables are filled with fine materials (e.g. natural or artificial sand). Water is flowing inside the table and its movement causes the formation of a "river" channel. The relief this material forms, the gradient of the table, the quantity, the intensity and the duration of the "rainfall", as well as the morphometric and physiographic features of the channel, can be changed at will. Therefore, students experiment with these system parameters and study the evolution of the phenomenon. The user of the artefact determines the velocity, quantity and duration of the added water in order to simulate the rainfall characteristics.

Water that flows into the channel, reshapes the initially and artificially formed relief in the say way that it would to in nature, however in a more quick way, allowing trainees to observe all the aforementioned processes and comprehend, for instance, the different zones (i.e. erosion, deposition and transportation zone) and processes, river meandering, delta formation etc. In this way, the initially formed channel is also changed.



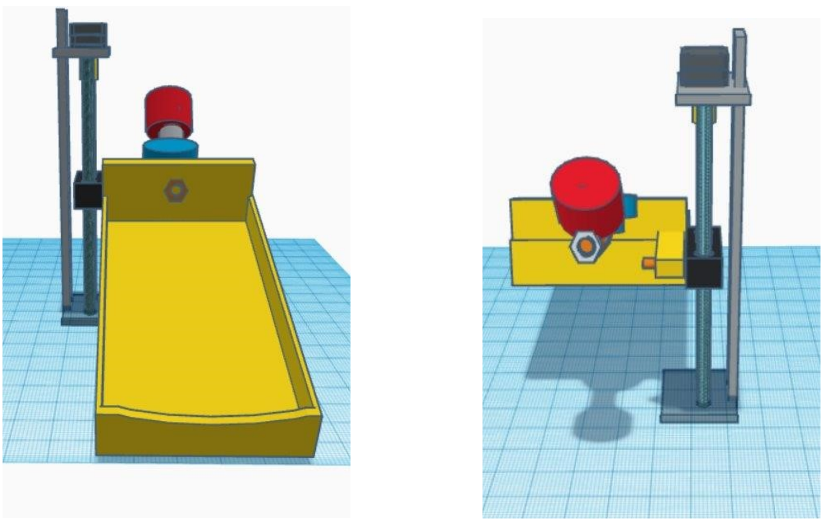
Shape 3. Surface runoff concepts (source: https://climate.nasa.gov/)

According to shape 3, students realize the surface runoff concepts and how river channels are formatted. Students built their own tables and experiment by tweaking parameters such as water flow and runoff table angle. They collect their data and record their observations to conclude how erosion is affected depending on the material they use, the obstacles that exist or by changing the slope of the surface runoff tables.



Shape 4. The side view of the runoff table for STEM experiment

Students use TinkerCAD (www.tinkercad.com), which is a free on line design and simulation tool, to design their experimental run off table. In shape 4 we depict the side view of their designs. Students save their designs and print the tables with a 3D printer, using flexible plastic material. In particular, the dimensions of the table is 80x100 cm. The two basic parameters are: 1) the angle, which elevates the table in Z – axis and 2) the water flow pressure, as controlled by a flow meter. In shape 5, we depict the front and rear view of the runoff table artifact, in which the elevation mechanism and the flow valve is obvious.

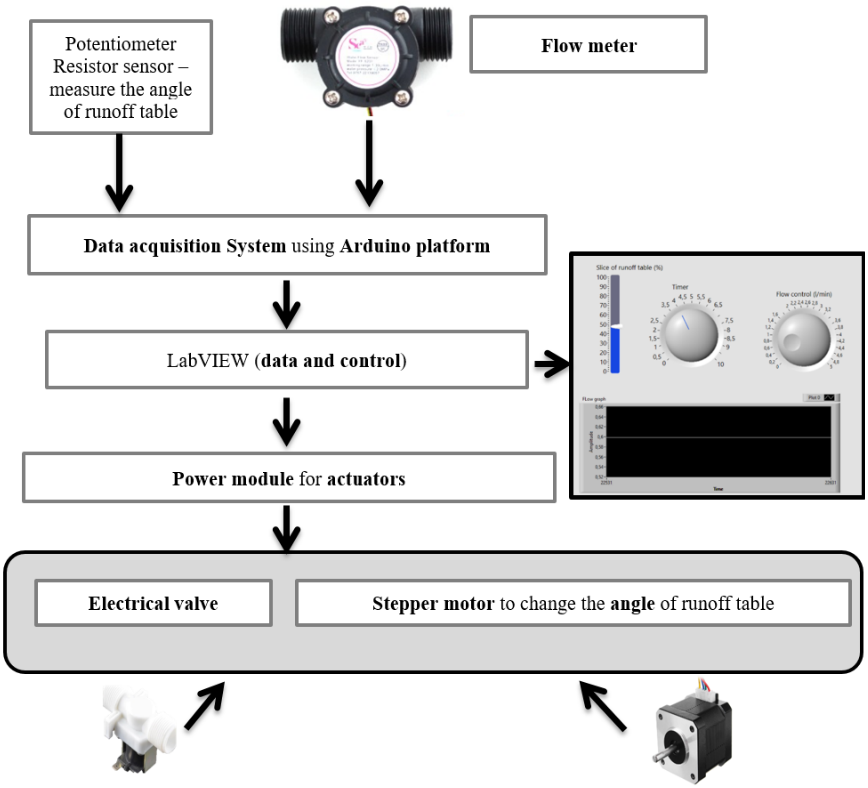


Shape 5. The front and rear view of the runoff table for STEM experiment

Following, students construct their design artifacts with the use of recyclable materials and 3D printer. Students extract their design file and use a 3D printer to construct the table / basin. The electromechanical materials needed for the construction phase are as follows:

- 1 x Flow meterQ Model: YF-S201, Sensor Type: Hall effect
- 1 x Electrical valve 12 V
- 1 x CNC Shield V3.0
- 1 x ARDUINO UNO
- 1x A4988 Driver
- 1x 4401 Stepper Motor
- 1 x Leaner potentiometer 10KΩ

The control / programming of the simulation process is done with LabVIEW. LabVIEW interface contains a set of virtual programming tools that helps users to easily program applications that receive data from an external environment. Additionally, LabVIEW uses NI VISA drivers to provide an interface with the external environment via the computer's COM serial communications port using RS – 232 protocol. Using LabVIEW's front panel, we have a graphical way, via which we can easily tune our system's settings. The block diagram, in shape 6, of the proposed STEM – based activity system for simulating runoff tables is as follows:



Shape 6. Block diagram of physical computing for runoff table artefact

Students through the control element of LABVIEW front panel, change the slope (i.e. angle) of the runoff tables. During Z – axis movement, students measure the slope of the artefact using a protractor. We choose not to automate the angle change process, so that the student can contribute to the system control process. To understand the erosion phenomenon process, students through LABVIEW's control element, adjust an analogue electric valve the water flow that is infused inside the table.

Conclusions

The surface runoff tables simulate the surface runoff processes that take place in the nature. In this paper, we use this concept to design and propose a STEM – compliant scenario, where students experiment with runoff parameters and comprehend the Earth's shape relief. This kind of tables is filled with materials like sand, water is dropped on the table, and the table's movement causes the formation of a "river" channel. We construct our runoff experiment table using 3D printed and we program and control the angle and the water flow with physical computing sensors and platforms. The student experiment with the process by determining the pressure, quantity and pressure of the added water, to simulate the rainfall characteristics. Different parameter values lead to different zones of erosion, river meandering and delta formation. STEAM activities in Geoscience raise the environmental awareness of students to a high level.

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