PROCEEDINGS OF SCIENCE

Design & Development of teaching materials for Introducing Wetting Models in Science Club

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Nanoscience and Nanotechnology (NS-T) are of the most rapidly emerging fields. Manipulation of the matter in the nanoscale has resulted in innovative products and concepts in the macroscale. Biomimetics especially, has utilized NS-T to create pioneering products, such as self-cleaning surfaces, super hydrophobic or hydrophilic materials, based on understanding and handling the wettability of surfaces. Wetting Models are used to describe various wetting states of a surface. Wetting models portray the different ways of a surface's wetting and the way the procedure is actually determined by its micro- and nano- roughness. Although a subject rarely encountered among educational interventions in Biomimetics, it provides fundamental context for comprehending phenomena such as hydro- and oleo- philicity and phobicity, the Lotus Effect, and the Rose Petal Effect. Their introduction is thus considered appropriate to occur in order to establish a solid theoretical background concerning the aforementioned phenomena. In the present study the design of teaching materials about Wetting Models addressed to Secondary Education is being described. To the means of structuring a specific teaching plan based on the instructional model of 5E's, Educational Reconstruction Model (MER) has been utilized. Decontextualizing scientific content and recontextualizing it, taking into account the characteristics and the factors affecting the learning process. As a result, six teaching modules have been created. Learning goals, association with the 9 Big Ideas of NS-T of these modules, as well as misconceptions expected to emerge will be presented.

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PoS(BPU11)254

1. Introduction

The term Nanoscience refers to the study and application of functional structures with dimensions of the nanoscale, i.e. from 1 to 100 nanometers. Nanotechnology is defined in a similar way referring to the technical applications arising from this science. With the help of constantly evolving technology, it is increasingly possible to explore the microscale [1]. Since 2000 more discoveries have come from Nanoscience and Nanotechnology (NS-T) than from any other scientific field. Its implications by 2030 are expected to reach or even overcome the digital revolution in terms of scientific and technological innovation achievements, investments, and wider impact on society [2]. Scientific research and technological advancement in the nanoscale has yielded state of the art achievements in every discipline applied. Given the above, the need to introduce NS-T thematics in both formal and non-formal education settings is imperative.

Biomimetics consists of a major application field of NS-T. Biomimetics is the study of nature and natural phenomena to understand the principles of underlying mechanisms, to obtain ideas from nature, and to apply concepts that may benefit science, engineering, and medicine [3]. This idea appeared along with mankind itself, however NS-T has opened new horizons in the field. Wetting Models describe the different wetting states of a surface and how it ultimately depends on its micro- and nano- roughness [4]. Although it is a subject not often found in curricula, it provides a fundamental framework for understanding phenomena such as hydro- and lipo-phobicity and philicity, the Lotus and Rose Petal effects. Thus, this subject is better introduced beforehand to the above-mentioned phenomena, aiming to install a solid theoretical background. Science clubs were chosen as suitable settings. Science clubs are extracurricular programs in which science is something that is practiced rather than something simply learned. By communicating science this way, participants discover, delve into more than just knowledge and explanations, and see science as a never-ending process that helps them understand the Nature of Science [5]. Their influence and contribution towards scientific literacy and the development of interest and positive attitude towards science is mentioned in various studies [6].

In this work, the introduction of wetting models is proposed for a Science Club, addressed to high school students. The Educational Reconstruction Model, MER was employed, while the teaching activities follow the 5E Learning Cycle instructional model.

2. Theoretical Background

2.1 Scientific Content

The scientific content concerning the wetting phenomenon was drawn from Bhushan's book "Biomimetics - Bioinspired Hierarchical-Structured Surfaces for Green Science and Technology" [4], and consists of the surface roughness, the contact angle and the four wetting models.

2.1.1 Surface Roughness

Roughness as a measure of a surface's texture (Figure 1) is calculated from the vertical deviations of its ideal completely smooth form. Roughness determines the interaction between the surface and the droplet.

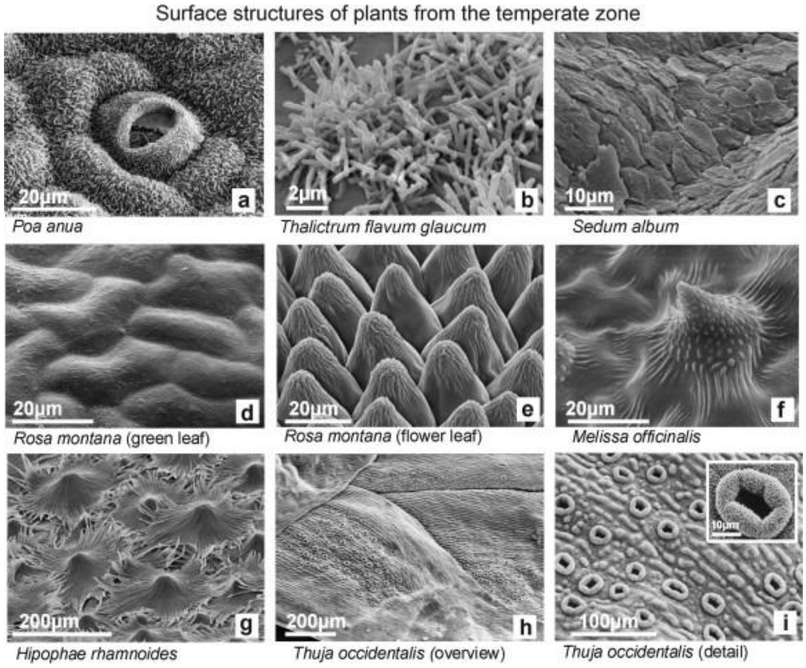

Figure 1: Examples of surface roughness SEM micrographs of plant surface of temperate habitats used for educational purposes in “Surface Roughness Module” [7].

2.1.2 Contact Angle

The defining parameter that affects wetting is the static contact angle which is formed between liquid and solid. Contact angle depends on the interfacial energies of the solid-liquid, solid-air and liquid-air interface, on the roughness of the surface, as well as on preparation and cleaning manner of the surface [8].

Shown in Figure 2 is the surface wetting state (non - wetting, low wetting, high wetting, perfect wetting) depending on contact angle.

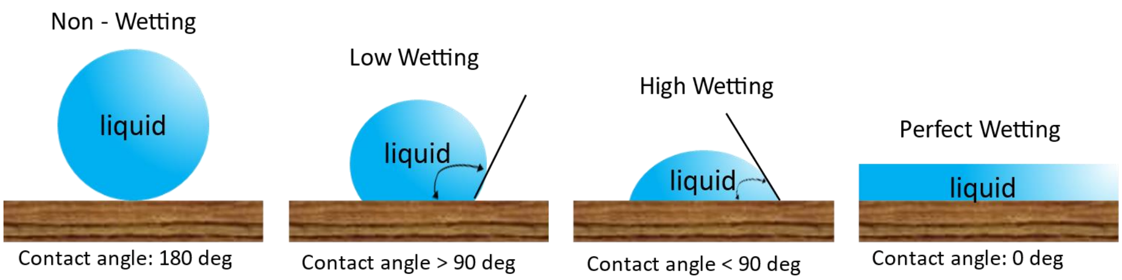

Figure 2: Contact angle of liquid on solid surfaces, adapted from [9].

One way to obtain the contact angle is by tallying up the capillary forces acting on the line of contact (also called triple line) and equating the sum to zero. By projecting the equilibrium forces onto the solid plane, one obtains Young's relation: $\gamma \cdot cos\theta_c = \gamma_{SO} - \gamma_{SL}$

where the three coefficients are the surface tensions at the liquid/air interfaces, solid/air, and solid/liquid, respectively [10] as illustrated in Figure 3.

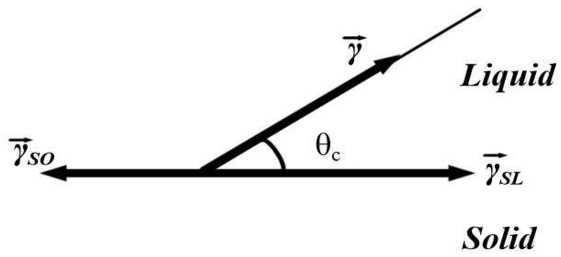

Figure 3: Determination of contact angle via forces, adapted from [10].

2.1.3 Capillary Length

There exists a particular length, l_{cap} (usually denoted as κ^{-1}), beyond which gravity becomes important. It is referred to as the capillary length. The capillary length is defined as $l_{cap} = (\gamma / \rho g)^{1/2}$, where γ is the liquid surface tension, ρ is the liquid density, and g is the gravitational acceleration [11]. The value of the capillary length is a composition of variable quantities. The value of surface tension will vary with temperature and the density difference will change depending on the fluids involved at an interface interaction [10]. In Figure 4 the difference in the shape of the droplet is demonstrated. During the activities described in this paper, the droplets created are considered of such size that gravitational forces can be neglected.

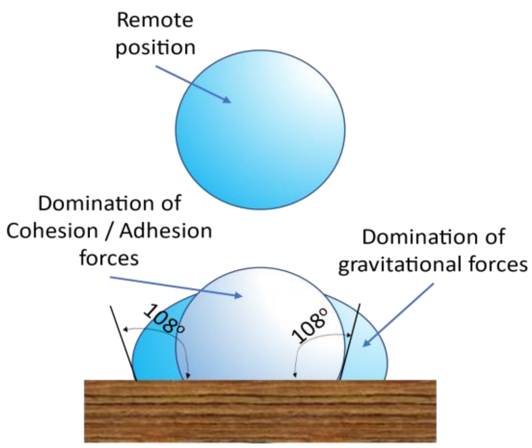

Figure 4: Gravitational forces flatten the drop and increase the wetted area with a constant contact angle. Image adapted from [12].

2.1.4 Wetting Models

There are four theoretical models used to describe the effect of roughness on a surface's wetting ability [4]. The Wenzel model describes homogeneous wetting, the Cassie – Baxter model describes heterogeneous wetting, while the Cassie model describes the agglomeration of fluid through capillaries in neighboring cavities around the droplet.

The model most often used that best describes naturally occurring wetting situations is a combination between the Wenzel and Cassie - Baxter model (mixed/impregnated model).

2.2 Models and Modeling

Models are alternative ways of representing a goal (e.g., a phenomenon, object, material, system, or relationship) [13]. They can represent a concrete or abstract goal. Models can be physical or computer-based, static or dynamic. The type of model used depends on both its purpose and goal. They must be able to describe, explain and/or anticipate some – but not necessarily all – aspects and behaviors of a goal. The balance between what a model can explain and what a model cannot explain is guided by its purpose. Therefore, each model is always a compromise that includes the modeler's choices as to which aspects of the goal should be emphasized. It is possible to create multiple models of the same goal that depict or emphasize different aspects of the goal. Models are not static entities that provide access to a "correct answer", but are constantly reassessed according to new scientific evidence, which leads to changes as the model evolves and new knowledge is incorporated into it [1].

The development of modeling theory has repeatedly proven to be effective for all educational levels in various scientific disciplines [13]. Its benefits in teaching Physics are manifold. In particular, there is a better perception of concepts in relation to traditional teaching, perceptions closer to the scientific way of thinking, strengthening of thoughtful and insightful research during the study, lower dropout rates, better performance, fair learning, in the sense that it benefits students of all levels of performance and the acquisition of skills useful in other science subjects [13].

The characteristics of models and modeling on which the design proposal that follows is based upon, are the following [14]:

1. A model is the expression in the physical world, with elements of the physical world and in various verbal and non-verbal ways, of the mental construction formed by the one who invents it. In other words, it is the externalization in an organized way and in a specific context, of the way in which the subject perceives a situation, a natural phenomenon, a process, etc.
2. Scientific models through their representations provide a framework not only of understanding but also of predictability.
3. They should have common points of reference with everyday experiences, to build the new knowledge on the previous and such structure as to minimize the possibility of creating or favoring alternative perceptions.
4. To this end, it must be made clear in their use that they represent a part of reality or an idea of it. Like any tool, if it proves unsuitable for the intended use, another one must be modified or constructed.
5. The modeling process has excellent metacognitive utility, and its review offers multiple benefits, the main one being the deepening of the concepts under negotiation.
6. Modelling, in addition to being a purpose, can also trigger further inquiry.

2.3 The Model of Educational Reconstruction (MER)

NS-T and Biomimetics are concepts quite difficult to grasp due to the complexity of their nature. Also, they are not part of the school curriculum worldwide. The additional factor of concerning phenomena that aren’t directly relevant to students' experiences, makes the need for reforming scientific knowledge into subject matter easily accessible of uttermost importance.

To the scope of this, MER was used for decontextualization of scientific content and the re-contextualization into content to be taught. MER, guided by the interdisciplinarity that characterizes scientific education, is described by three interrelated and interdependent processes: Analysis of content structure which includes two processes which are closely linked, clarification of subject matter and the analysis of educational significance. Research on teaching and learning which consists of empirical studies on various features of the particular learning setting, including pre-existing knowledge, misconceptions, interests, motivations, skills, etc. Development and evaluation of instruction which concerns the design of instructional materials, learning activities, and teaching and learning sequences [15]. The three components of the Model of Educational Reconstruction are schematically shown in Figure 5.

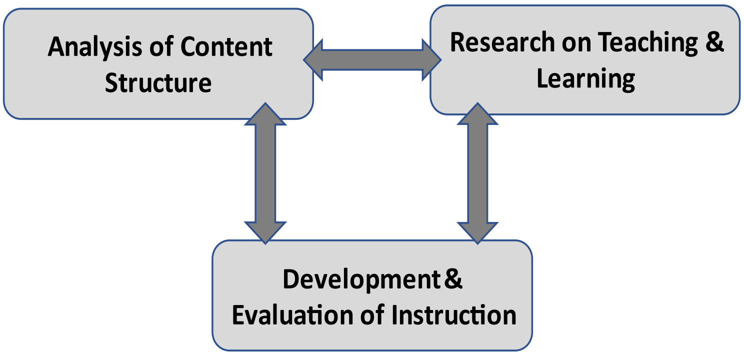

Figure 5: The three components of the Model of Educational Reconstruction, adapted from [15].

2.4 Instructional Model

The designed teaching materials were based upon the instructional model of 5E's as described below.

The 5E Instructional Model [16] can be used to design a science lesson, and is based upon cognitive psychology, constructivist-learning theory, and best practices in science teaching [17]. The cycle appears in Figure 6 and consists of cognitive stages of learning that comprise engage, explore, explain, elaborate, and evaluate. Its use helps students' conceptual change through interconnection and reciprocity with their peers and the learning environment. Their interpretation of objects and phenomena is internalized in terms of conceptual understanding [18].

Science teachers and curriculum developers may integrate or apply the model at several levels. It can be used as an organizing pattern of a sequence of daily lessons, individual units, or yearly plans [18]. Each phase of the 5E Instructional Learning Cycle is described below.

Figure 6: The instructional model of 5E's.

Engagement: In this first phase of the cycle, the teacher aims to assess students' prior knowledge and/or identify possible misconceptions. This is a student-centered phase. During this phase, students are stimulated and motivated to learn more about the upcoming topic.

Exploration: The exploration phase provides students with a common, concrete learning experience. This phase is also student-centered and incorporates active exploration. Students are encouraged to apply process skills, such as observing, questioning, investigating, testing predictions, hypothesizing, and communicating, with other peers. Also, students are encouraged to develop skills and concepts.

Explanation: The explanation phase enables students to describe their understanding and pose questions about the concepts they have been exploring. Questions will arise and students should express their own explanations and ideas. This phase includes clarification of misconceptions that may have emerged during engagement or exploration phases. The teacher can provide formal definitions, notes, and labels, and also use audiovisual aids to help students understand. The students should be able to clearly explain the basic concepts to the teacher and their peers.

Elaboration: The activities in this phase of the learning cycle should encourage students to apply their new understanding of concepts, while reinforcing new skills. Students are encouraged to share their understanding with their peers, or to design new experiments or models based on the new skills or concepts they have acquired. Students may conduct additional investigations, develop products, share information and ideas, or apply their knowledge and skills to other disciplines.

Evaluation: In this approach both formal and informal assessments are appropriate and should be included. Assessment should be viewed as an ongoing process. Teachers observe their students as they apply new concepts and skills. They also look for indications that students have changed or modified their approach on the subject. Students may also have the opportunity to conduct self - assessment or peer-assessment. However, the evaluation may also include a summative experience such as a quiz, exam, or writing assignment.

This instructional model constitutes a flexible and dynamic circle of processes. It should be noted that this is not a linear process and that teachers often have to go back into the cycle sometimes at the expense of time. The cycle does not have to be completed in one day or in one teaching unit. The model is designed to facilitate conceptual change and contribute to more consistent and coherent science instruction [18].

3. Materials & Methods

For the design of teaching materials, the scientific content was initially identified, and the wetting models were defined as the main objective. The concepts required by students to comprehend were detected and connected with elements of NS-T based on the categorization of Stevens et al. [1]. The scientific content was modified into content for instruction based on the MER model. To draw a specific plan for the design and development of suitable teaching materials, internet research was conducted. The terms "Biomimetics", "education", "non-formal education", "science club", "models", "wetting", as well as a combination of the above, both in Greek and English, to locate relevant scientific literature and articles were used. Through this research difficulties and misconceptions of students were identified and taken into account.

PoS(BPU11)254

In several cases students use images from original research papers. These images are kept in the original form and are used for educational purposes in an attempt to familiarize students with actual scientific research findings. Using copyrighted images for teaching and education is generally considered fair use, which does not violate copyright laws and is allowed under fair use exemptions (U.S. Code, Title 17, Chapter 1, Section 107). All images used in the paper are properly cited.

4. Results & Discussion

Results of this work are divided into two subsections. In the first section the didactic transformation of the scientific content is presented. The core element is identified and the connection with the big ideas of NS-T [1] is stated.

In the second subsection teaching units and learning objectives of each one, as they were designed based on the above, are presented and analyzed. Results from this process are discussed.

4.1 Didactic Transformation

Based on the methodology described by MER, the consecutive didactic recontextualization took place, which yielded in six modules. In the following subunits the core element which reconstruction was based upon, as well as misconceptions and prerequisite knowledge will be presented, given the fact that they are essential to the design of the teaching material.

4.1.1 Core Element

Core element of the topic is the *models used to describe how the roughness of a surface affects its wetting*. The appropriate approach was considered to be the elementarization of the core element to its main components and further analysis of the sub-elements (top-down approach). This subtractive process ensures that only items of direct interest will be preserved [19].

The identified elements are the roughness of the surface, the way the roughness determines the contact angle and last the four wetting models. There was a correlation of these three elements to the 9 Big Ideas (B.I.) of NS-T, as identified by Stevens and her associates [1], resulting in the following correspondence:

Table 1: Correlation of the three main elements with the Big Ideas of Nanotechnology.

Roughness of the surface	2nd B.I. of NST: Structure of matter
Contact angle	2nd B.I. of NST: Structure of matter
Wetting Models	8th B.I. of NST: Models and Simulations

4.1.2 Students' Misconceptions & Prerequisite Knowledge

Introduction of any new knowledge requires the aggregation of students' misconceptions, and prerequisite knowledge. The relevant misconceptions detected through research and the prerequisite knowledge of children in secondary education are presented below.

<u>Surface Roughness</u>: Alternative ideas concerning the first module refer to the hierarchical structure of matter. Students are taught about the particle nature of matter in fifth grade. However, the hierarchy in construction is dismissed from the description of a material [1]. Thus, the way it determines the properties that each layer displays, and how it ultimately contributes to the

macroscopic properties that are presented is being ignored. Also, difficulties regarding the conceptual distinction between homogeneous and uneven roughness are expected to emerge.

Wetting models: Alternative ideas in this module concern students' perceptions of scientific models. Students think that models differ only in scale and not other properties. They also believe that models are representations of events and not tools of interpretation and prediction. The important role of models and simulations in the process of scientific research is not acknowledged. The existence of various types of models (mathematical, computational, and symbolic) is usually being ignored.

The prerequisite knowledge that students are considered to possess is the hierarchicality in the construction of matter (atoms - molecules - molecular and hypermolecular complexes), as well as everything regarding measurement of angles. It is considered that they know that there is matter that cannot be observed with the naked eye but are unfamiliar with the scale order of micro and nano magnitude.

4.2 Teaching Units

Chosen learning objectives for the current study and corresponding modules developed appear on Table 2.

Table 2: Structure of the content to be taught with corresponding learning objectives.

Modules	Learning Objectives
1st: Introduction to the concept of wetting	1. To understand the concept of wetting 2. To understand that the droplet's shape indicates the wettability of the surface
2nd: Contact angle	1. Understanding the concept of contact angle and how surfaces are characterized by it's value 2. Comprehension of wetting regimes
3rd: Surface roughness	1. To understand the order of micro & nano magnitude 2. To understand the correlation between wetting and hierarchical roughness 3. To understand the dependency of characteristic properties on surface's geometrical features and sample size
4th: Wetting Models	1. Understanding the importance of models and their use in science 2. To distinguish the four wetting models and to identify differences between them 3. To be able to distinguish when each model is detected (homogeneous – uneven wetting, rough - smooth surface)
5th: Application of Knowledge	1. Ability to qualitatively describe the wetting phenomenon 2. Recognize the Cassie – Baxter and Wenzel model on each surface respectively
6th: Evaluation	Evaluation does not include learning objectives

4.2.1 Engage Phase: Introduction of Wetting Module

The first activity corresponds to Engagement at 5 E's cycle as it aims to introduce the notion that wetting is a surface's interaction with a liquid (water in this case). Everyday objects and materials that students are familiar with were chosen. Students to be asked to pour droplets of colored water on those objects so that they can observe the droplet's expansion and shape and are expected to notice how they are interconnected. In some objects, waterproofing spray was partially applied, and the shape of the droplet was observed before and after the application. Some examples of materials which can be used in this activity are shown in Figure 7. Note: in Figure 7.d plum has been rubbed off of its external protective layer which consists of Epicuticular micropapillae. After this activity the students can formulate their thoughts and ideas via a discussion. Students' misconceptions concerning interactions between surface and liquid are expected to emerge during this activity and clarification of the concept of wetting is to follow.

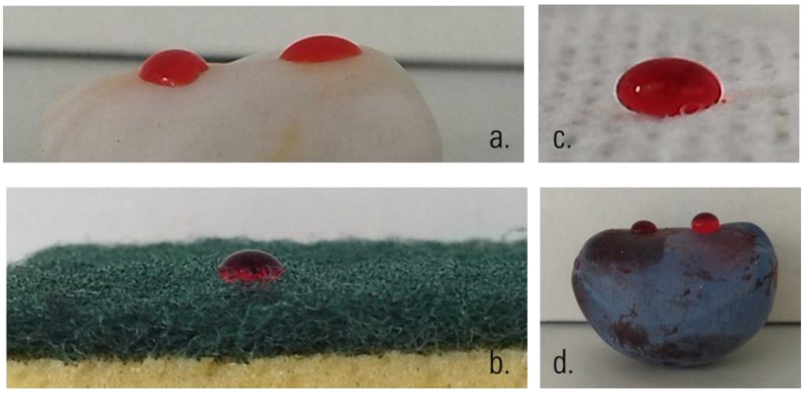

Figure 7: Droplet application in various treated and non-treated different surfaces. a) small rock partially treated with waterproofing liquid, b) kitchen sponge, c) Dye Trapping Sheet and d) plum partially rubbed.

4.2.2 Explore Phase:

4.2.2.1 Contact Angle Module

Exploration phase of the 5Es begins with the second module concerning contact angle. A magnifying glass in physical or electronic form (application) can be used in order to detect the contact angle formed between the droplet and each surface observed in the first activity (as shown in Figure 8). When the appropriate photographs are taken, the contact angle can be measured using a physical or electronic protractor.

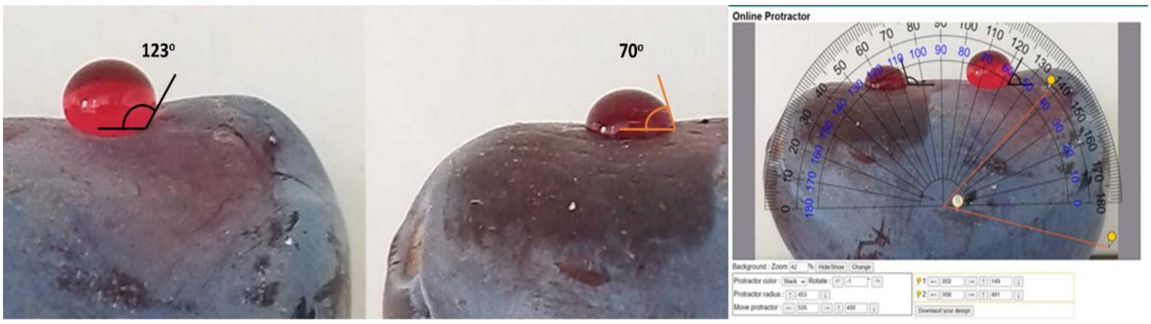

Figure 8: Measurement of the contact angle between liquid and solid surface on a plum.

Through discussion the correlation between contact angle, droplet size and surface structure are expected to emerge. At this point it could also be possible to expand the discussion on the fact that as surface roughness increases, hydrophilic substrates appear even more hydrophilic, while those hydrophobic appear even super-hydrophobic [10].

The aim of this activity is to highlight the decisive role the surface's structure plays in shaping the droplet and how this is indicated by the contact angle. This can trigger a discussion about surface structure (roughness) and act as a connecting link to introduce the concept of surface roughness and how it is described in micro and nano scale, in the next module.

4.2.2.2 Surface Roughness Module

Exploration phase continues at the third module as the concept of surface roughness and the orders of magnitude of micro and nano scale are being investigated after a brief introduction.

Initially, students to be encouraged to express their ideas about characterizing a surface as smooth or rough. Then the order of magnitude of micro and nano scale is presented and it is clarified how the surface's micro and nano structure determines its roughness. To visualize this, the teacher presents a tableau where lego blocks can be assembled on. Lego blocks are used to model nano and micro surface features. These blocks are to be handed to the students asking them to construct a model of a surface with different rates of micro and nano formations with escalating complexity. Some examples of models of surfaces constructed with lego blocks are shown in Figure 9.

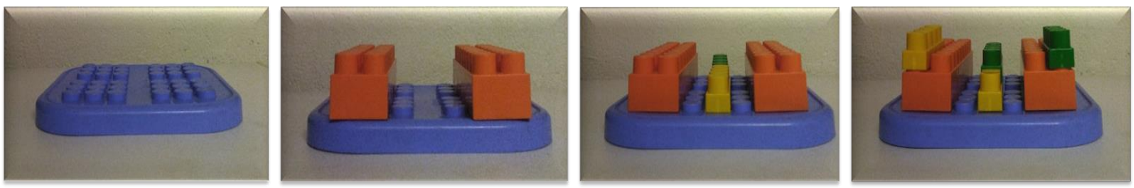

Figure 9: Four models of roughness of surfaces with increasing complexity, made with lego blocks.

After finishing familiarizing themselves with the models and the concept of surface roughness, students are asked to observe with a usb microscope the different surfaces that they consider smooth. Next, the criteria according to which a surface is characterized as smooth or rough are being clarified. These are the height of the micro/nano protrusions and the distances between them (deviations from the ideal smooth surface).

In this module, students are expected to understand that there are no completely smooth surfaces and that on the micro or nano scale all surfaces, even seemingly smooth ones, show some kind of roughness. To reinforce this, SEM photographs of various plant leaves demonstrating their surface texture could be used to help students see surfaces on a microscopic level, as a scientist is able to (Figure 1). Furthermore, through discussion of their observations, students are expected to associate the wetting of a surface with hierarchical roughness that characterizes it in the micro and nano scale, creating the conditions for introducing the next module.

4.2.3 Explain Phase: Wetting Models Module

During the explanation phase the teacher presents the scientific concept of models as descriptive and predictive means and then attempts to make the connection with wetting models describing different wetting states. The different wetting states described by each model, and how microstructure is used to distinguish them, are explained.

This module discusses the nature of models and their use in science and scientific research. The concept of models in science is clarified and it is stated again that there are no smooth surfaces in nature and that this is a model used by scientists to simplify more complex situations.

Afterwards the four wetting models are presented along with visual representation which depicts the characteristics of each one, as shown in Figure 10. Students are asked to observe the differences between the models (inflow of the droplet into the micro/nano protrusions, droplet shape, relative size of the droplet and protrusions).

The characteristics of each wetting model are explained, and emphasis is placed on the interaction of the droplet with the surface as a function of the following factors/ variables:

1. micro and nano roughness
2. the size of the droplet
3. the contact angle (which is determined by the previous 2)

Students are then asked to construct/represent with balloons of different sizes and blocks their own models and then to match their construction with one of the theoretical wetting models described earlier (Figure10). This activity enables students to express their assumptions and pose questions about the concepts they have been exploring. In this context the students are asked to take pictures of the models they constructed, measure the contact angle, and correlate it with the wetting state.

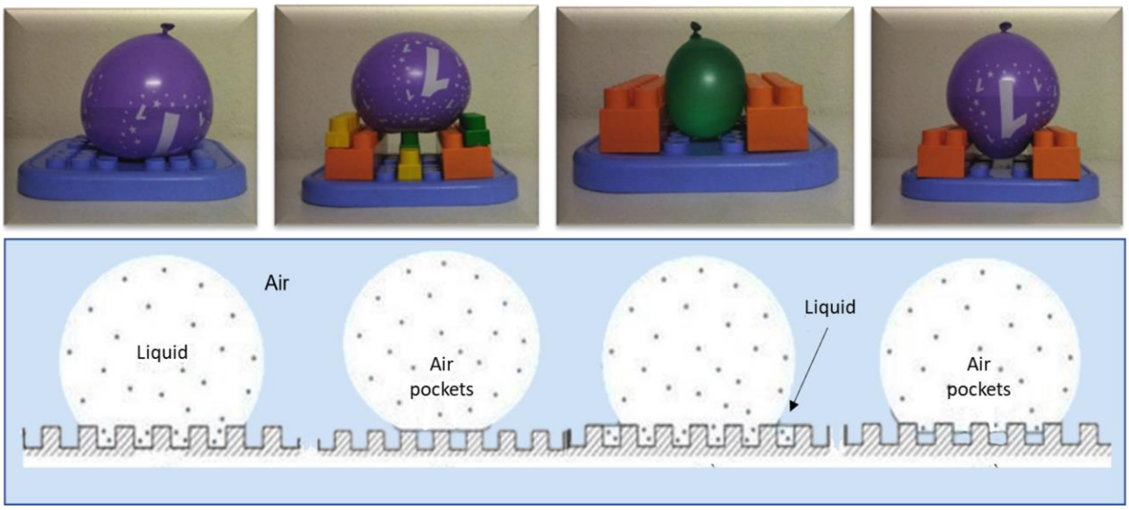

Figure 10: Representation of wetting models with balloons partially filled with water and lego blocks. a) Wenzel interface, b) Cassie-Baxter interface, c) Cassie - impregnated interface and d) mixed/impregnated interface, adapted from [4].

This module aims to understanding the importance of models as means of description and prediction in science. Through activities of building (constructing) their own models, students become familiar with the use and utilization of scientific models. From the models made, it can be deduced whether the students have understood the function of the four wetting models and the differences between each model. In the event that a structure is not in correspondence with any of the theoretical models describing wetting, is a great opportunity to discuss and renegotiate the incongruous model with emphasis on its differences from the scientific model. Finally, by photographing the models built, measuring the contact angle in the photographs, and correlating

PoS(BPU11)254

it with the wetting state, the interconnection of the contact angle with the roughness of the surface should become apparent.

4.2.4 Elaboration Phase: Application of Knowledge Module

In the elaboration phase students to be encouraged to apply their new understanding of the wetting phenomena by connecting wetting models with wetting situations observed on surfaces they are familiar with. The teacher should take care to provide leaves or other natural surfaces. Preferably ones which will result in wetting phenomena similar to the leaves of lotus and rose petal (as described by Cassie - Baxter and Cassie impregnated interface models respectively). Students are asked to apply droplets of water on two different surfaces and take pictures from the side using the USB microscope. Then to observe the contact angle of the droplet and give their own estimate of which model best describes the wetting in each case. Students' ideas are recorded and discussed in class. It is expected to conclude that no model accurately describes situations encountered in nature (not ideal) and that in any case the wetting state is essentially described by combined elements of the four wetting models.

Leaves and surfaces can be used that simulate the properties of the lotus leaf and the rose petal as these two surfaces have special characteristics and it is considered appropriate to introduce them as phenomena to the students that they may be able to study in later lessons. An attempt made is shown in the linked videos https://youtu.be/Sq3FuPNhVWQ (Figure 11a) https://youtu.be/ky96ic4q_4M (Figure 11b).

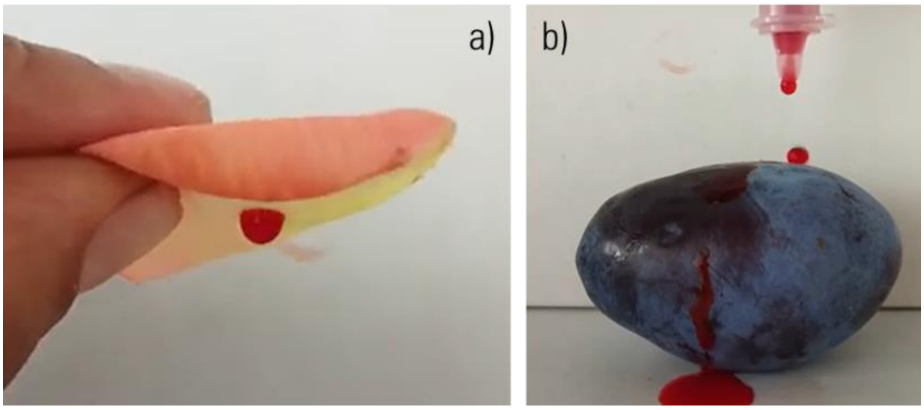

Figure 11: Screenshots of the aforementioned videos showing Rose petal and lotus effect phenomenon using a common rose petal and a plum.

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Students are expected to be able to qualitatively describe the phenomenon of wetting, and recognize the Cassie Baxter and Cassie impregnated interface models on the leaves of the lotus and rose petal. Through observing everyday surfaces under a microscope and trying to match wetting models with them, students should be able to understand that models are a means of description, explanation and prediction and are not found in nature as actual situations.

4.2.5 Evaluation Phase

At the evaluation phase students could reflect on the surfaces examined at the first module. Acquainted knowledge to be applied to identify each model and present their findings to the class.

Applying the new knowledge from the previous modules, possible misconceptions and misunderstandings can emerge. To assess their comprehension, they are asked to apply what they have learned throughout the activities on the surfaces used in the first module. At the beginning, those surfaces were used to engage students. Later on were categorized according to surface roughness, afterwards the contact angle formed, and finally the model best describing their wetting state. As homework assessment they could create a presentation explaining the whole process to the scope of critical reflection that will serve as a metacognitive activity. They are encouraged to collaborate with each other and to conduct their own research. The presentation should include theoretical support of their conclusions (why this particular wetting state is described best by x, y, z model).

5. Conclusions

In order to design and develop teaching materials for introducing wetting models, scientific content was elementarized and MER was utilized to convert it into content to be taught in secondary education (grades 9 and above) according to the 5E's instructional model. A 5E plan helps set-up lessons in a manner that supports active engagement of students, incorporates cooperative learning, and de-emphasizes the rote memorization of facts.

Through this process six modules emerged, concerning the introduction of wetting, the contact angle, the surface roughness, the four wetting models, the implementation of knowledge, and evaluation. According to MER, during recontextualization, characteristics of the learning environment were taken into account, as well as the necessary prerequisite knowledge and alternative conceptions related to each module. Non-formal education setting was chosen for the implementation, more specifically a science club, since this kind of knowledge is not included in the formal analytical program of several countries. Science clubs are considered to contribute to the communication of science and the development of a positive attitude towards it, because in those learning environments scientific literacy is promoted.

This paper presents a proposal for the design of teaching materials that has not been implemented. These resources can be improved and adapted according to the needs of teachers and students who will use it. Some suggestions for expanding the modules are the inclusion of more modules in order to encompass overall the concept of wetting. A visit to an electron microscopy laboratory could also be incorporated in teaching. Students could not only observe surfaces through electron microscopy, but also see how measurements are made using scientific tools.

Biomimetics has in recent years offered products and innovations in areas that fundamentally affect life around us. Manufacture and manipulation of nanoscale structures besides the benefits, also have effects on the environment that have not yet been studied in the long run. To face this new reality, the ability of critical thinking and informed evaluation is essential to decision making of the future citizenhood.

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PoS(BPU11)254

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