PROCEEDINGS OF SCIENCE

Teaching Activities for the Super-hydrophobicity and Adhesion Observed in Rose Petals due to their Hierarchical Structure

Ioannis Kalantzis[a,1]* **and Euripides Hatzikraniotis**[b]

a Program of Post Graduate Studies on "Didactics of Physics and Educational Technology", Department of Physics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece,

b Department of Physics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

E-mail: iokalant@physics.auth.gr, evris@physics.auth.gr

Nature has developed materials, objects and procedures that occur in the macro-scale as well as the nanoscale. The results of millions of years of biological evolution and the optimized "techniques" developed by the organisms are available to scientists who seek new ideas by studying the solutions provided by nature. The scientific field that allows man to imitate nature and to develop nanomaterials, nanomachines and processes with various desired properties is called Biomimetics. The widespread use of Nanotechnology products by our modern technological society and the growing need of the industry for a working force specialized in this field are two of the main reason for the introduction of Biomimetics and Nanotechnology in school curricula.

This paper presents a proposal for the introduction in Secondary Education of a highly popular phenomenon from the field of Biomimetics known as the Rose petal Phenomenon. This is the phenomenon of strong adhesion of small water droplets on some superhydrophobic variants of rose petals. By studying the phenomenon, students have the opportunity to come in contact with several big ideas of science, to understand the possible misconceptions they might have, to get acquainted with scientific processes, scientific instruments, scientific models and to develop important skills. The scientific content the Rose petal Phenomenon comes from Bharat Bhushan's book "Biomimetics: Bioinspired Hierarchical-Structure Surfaces for Green Science and Technology". For the effective integration of this subject in the school classroom, the Model of Educational Reconstruction MER was applied. Following a constructive epistemological orientation, the students' perceptions, interests, needs and expected difficulties were taken into account. The results of the application of the MER model are the creating of 5 teaching activities and their learning objectives to get students acquainted with the phenomenon as well as the science behind it.

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[1]*Speaker

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1. Introduction

Nature has developed materials, objects and processes that operate from the macroscale up until the nanoscale. The emerging field of Biomimetics allows humans to mimic nature and how it functions to develop nanomaterials, nanodevices and processes with various desired properties (Bhushan, 2016). Bio-inspired man-made materials are even environmentally friendly and are being explored for even more commercial applications. With the continued understanding of mechanisms related to living nature species and the development of new materials and nanofabrication techniques, rapid developments are expected within the next decades.

Rose petal phenomenon is the ability of certain rough surfaces to have a high contact angle simultaneously with high adhesion (large contact angle hysteresis) with water (Bhushan & Nosonovsky, 2012). By studying topics of Biomimetics such as the rose petal phenomenon, students have the opportunity to come into contact with several big ideas of science, to realize their own alternative concepts, to apply scientific procedures, to use measurements from modern scientific instruments, to get to know scientific models and develop important skills (Stevens et al, 2009). Getting to know the hierarchical structure of the surface of a rose petal is essential for the students to understand the complexity displayed by the surfaces of bodies in general. Superhydrophobic surfaces with strong adhesion, such as the rose petal, enables a variety of applications related to people's daily lives, such as their use on the inside of the airplanes to prevent condensed water droplets from falling on passengers.

In this work a proposal is developed for the introduction of the rose petal effect in Secondary Education for senior high school students through the educational reconstruction of the scientific content and the development of appropriate instructional materials and collaborative activities.

2. Theoretical Background

Historically, Otto Schmitt was the first to refer to this branch of Science as Biomimetics (Schmitt, 1969). Otto Schmitt was a scholar whose doctoral research was an attempt to produce a physical device that clearly mimics the electrical function of a nerve. By 1957, the concept of Biomimetics had been conceived as an overlooked (but highly significant) inverse of the classical concept of Biophysics. Later the word *Bionics* was used by Jack Steele of the US Air Force in 1960. By this word he defined the science of systems that have some function copied from nature, or that they exhibit characteristics of natural systems or even their analogues. The word made its first public appearance in Webster's dictionary in 1974 along with the following definition (Harkness, 2002):

> *The study of the formation, structure or function of biologically produced substances and materials (such as enzymes or silk) and biological mechanisms and processes specifically for the purpose of synthesizing similar products by artificial mechanisms that mimic natural ones.*

2.1 Scientific Content for the Rose-petal effect

Hydrophobicity is the physical property of a surface where a water droplet is seemingly repelled (Ben-Na'im, 1980). In contrast, hydrophilic surfaces attract the water. Superhydrophobic surfaces are highly hydrophobic, i.e., extremely difficult to wet. The contact angles of a water droplet on a hydrophobic surface is more on an superhydrophobic material exceed 150° (Wang, Shutao & Jiang, 2007). Different kinds of wetting behaviors are observed in nature, for example the lotus leaf which is a superhydrophobic surface with a low hysteresis contact angle. Unlike the lotus leaves, there are some species of rose petals that exhibit superhydrophobic behavior with a high contact angle hysteresis. Certain rose petals are known to be superhydrophobic with high adhesion. On the other hand, there are rose petals which are superhydrophobic with low adhesion similar to lotus leaf. Adhesive and cohesive (intermolecular) forces define the degree of wettability. Cohesive forces affect in-between the same type of molecules, whereas the adhesive interaction is between unlike molecules. The balance between these forces is what defines the degree of wettability.

So, while a drop of water can very easily roll off the superhydrophobic surface of a lotus leaf, it remains “pinned” to the surface of the rose petal. Therefore, there are several modes of wetting of a rough surface, and as a result wetting cannot be characterized solely by a single number such as the contact angle (CA) (Figure 1.a). Contact angle hysteresis (the difference between the advancing and receding contact angle, Figure 1.b) is another important parameter which characterizes wetting.

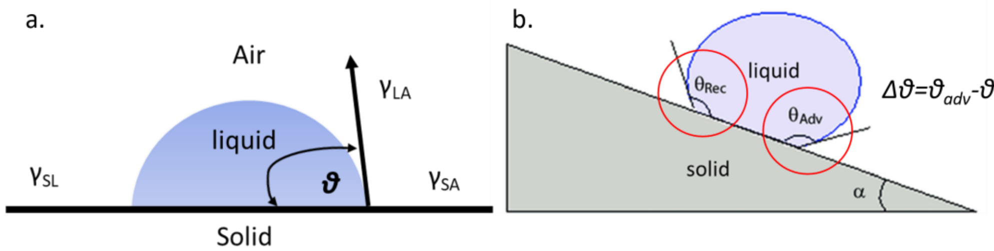

Figure 1: Contact angle θ and Contact angle hysteresis (adapted from *a.* Bhushan, 2010 and *b.* Toosi et al., 2017)

Wetting of a solid is dependant upon the adhesion of water molecules to the solid. On the one hand, a high contact angle is a sign of low liquid-solid adhesion. On the other hand, though, low contact angle hysteresis will provide us with the information that there is a low liquid-solid adhesion. Therefore, it is possible to have a high contact angle surface, making it superhydrophobic, that presents as well a large contact angle hysteresis making the superhydrophobic surface strongly adhesive to water (Bhushan & Her 2010, Chang et al. 2009). The so-called rose petal phenomenon is exhibited by a surface that has a high contact angle but also a large contact angle hysteresis and strong adhesion to water.

Bhushan and Her (2010) studied two kinds of superhydrophobic rose petals, Rosa Hybrid Tea cv. Bairage and Rosa Hybrid Team cv. Showtime. The surface roughness of the two rose petals was measured with the AFM and the resulting peak-to-base height of bumps, mid-width, peak radius and bump density are summarized in Table 1.

Table 1. Surface roughness statistics of the two rose petals (Bhushan & Her, 2010)

	Peak-to-base height (μm)	Mid-width (μm)	Peak radius (μm)	Bump density (1/10,000 μm2)
Rosa cv. Bairage	6.8	16.7	5.8	23
Rosa cv. Showtime	8.4	15.3	4.8	34

The data indicates that the low adhesion specimen (Rosa, cv. Showtime) has higher density as well as height of the bumps on its surface, indicating that the penetration of water between the microbumps is less likely. For a hierarchical structure with small bumps on top of larger bumps, similar to the surface of the rose petal, a large number of scenarios are available and they are summarized in Table 2 and Figure 2.

Table 2. Different regimes of wetting of a surface with dual roughness (Bhushan, 2012)

	Air in microstructure	**Water under droplet in microstructure**	**Water impregnating microstructure**
Air in nanostructure	Lotus, high CA, low CA hysteresis	Rose, high CA, high CA hysteresis	Rose-filled microstructure
Water under droplet in nanostructure	Cassie, high CA, low CA hysteresis	Wenzel, high CA, high or low CA hysteresis	Wenzel-filled microstructure
Water impregnating nanostructure	Cassie-filled nanostructure	Wenzel-fiiled nanostructure	Wenzel-filled micro and nanostructure

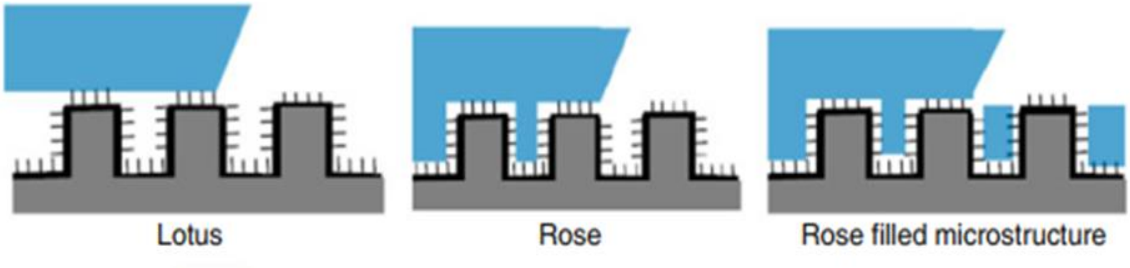

Figure 2. Schematics of three wetting scenarios for a surface with hierarchical roughness, as mentioned in Table 2 (adapted from Bhushan, 2012)

Bhushan and Her (2010) conducted a series of experiments designed to decouple the effects of the micro and nanostructures by attempting to replicate the same hierarchical structure and observe the same phenomenon that can be observed on the surface of the rose petal. They synthesized microstructure surfaces with pillars out of epoxy resin. Surfaces with a pitch (the periodicity of the structure of the pillars) of 23, 105 and 210 μm and with the same diameter (14 μm) and height (30 μm) of the pillars were produced. Afterwards, nanostructures were formed on the microstructured sample by self-assembly of the alkane n-hexatriacontane ($CH_3(CH_2)_{34}CH_3$), which was deposited by a thermal evaporation method. To fabricate the nanostructure, various masses of n-hexatriacontane were coated on a microstructure. The nanostructure is formed by three-dimensional platelets of n-hexatriacontane. They are randomly distributed on the surface, and their shapes and sized show some variation.

In Table 3, all the measurements of the contact angle as well as the contact angle hysteresis are amassed for man-made surfaces with various micro and nanoroughness. With the help of this data, we can accordingly determine the wetting model that each surface with the according characteristics will present.

Table 3. CA and CA roughness for surfaces with various roughness (Bhushan & Her, 2010)

Mass of n-hexatriacontane (μg/mm²)	**Pitch**					
	23 μm		105 μm		210 μm	
	CA	CA hysteresis	CA	CA hysteresis	CA	CA hysteresis
0.1	164°	3°	152°	87°	135°	45°
0.12	165°	3°	153°	20°	135°	45°
0.16	166°	3°	160°	5°	150°	12°
0.2	167°	3°	168°	4°	166°	3°

The contact line, also known as the three-phase contact line, is a line of intersection of three phases: solid, liquid, and gas. The contact line moves on the substrate until the total energy of the contact line reaches its minimum value, which is the thermodynamic equilibrium state. In this dynamic condition, the contact line is defined as the dynamic contact line.

The angle between the liquid–air interface and liquid–substrate interface at the dynamic contact line is known as the dynamic contact angle (θ_D). When the dynamic contact line reaches the equilibrium state, the dynamic contact angle becomes the static contact angle (θ_0).

There are two mechanisms for contact line dynamics: spontaneous and forced. In the spontaneous mechanism, the contact line moves on a substrate to reach the equilibrium state without any external driving force. In spontaneous mode, the capillary force and gravity play key roles in inducing the motion of the contact line on the substrate to reduce the dynamic contact angle to achieve the minimum energy value in the equilibrium state (static contact angle)

In the forced mechanism, the contact line dynamics are governed by an external driving force (or forces). In forced contact line dynamics, the balance of the forces is between the tendency of the contact line to achieve the equilibrium condition and the external force(s) to induce the contact line to deviate from the equilibrium condition. The forced contact line dynamics consists of two modes, advancing and receding contact lines dynamics. In advancing contact line dynamics, the dynamic contact angle is denoted as the advancing dynamic contact angle (θ_A). In receding contact line dynamics, the dynamic contact angle is denoted as the receding dynamic contact angle (θ_R). The physics of the dynamic contact line is conventionally defined in terms of the relation between the dynamic contact angle (θ_D) and the contact line velocity (U). The contact line velocity depends on the mode of contact line motion: spontaneous or forced. In forced contact line motion, the contact line velocity can be controlled to be constant. In spontaneous contact line motion, the contact line velocity might not be constant, such as a droplet spreading on a smooth glass surface in which the contact line velocity reduces as the dynamic contact angle decreases until the droplet reaches the equilibrium state (Mohammad Karim et al., 2022).

When the motion of the contact line is extremely slow, we observe that there is a difference between the contact angles of a liquid with the substrate, depending on the direction of the motion of the contact line. This effect is due to the presence of surface roughness or chemical inhomogeneity on the solid surface. There is an advancing θ_A contact angle (more air across the rough surface in front to traverse; thence less wetting, $\theta_A > \theta_Y$) and a receding θ_R contact angle (more water across the rough surface left behind by the heading part; thence more wetting, $\theta_Y > \theta_R$), where θ_Y is contact angle contained in Young's formula when we place a liquid drop on a clean, planar solid surface (thoroughly static case).

2.2 The model of Educational Reconstruction (MER)

The Model of Educational Reconstruction (MER) was developed as a framework for improving Science Teaching (Duit et al., 2012). It follows a constructive epistemological orientation that takes into account both students' perceptions and the interpretation of the scientific content. The understanding that students have already developed before the start of class are not seen as obstacles to learning but as starting points and mental tools with which they can expand on. The structure of scientific content is treated as the unanimous agreement of the scientific community and academic writings as descriptions of concepts, principles and theories and as impressions of reality itself.

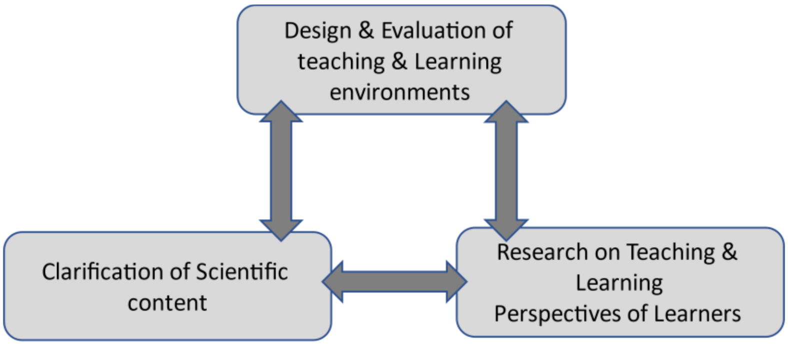

Figure 3. The three components of MER (adapted from Dannemann, 2017)

The MER model consists of three major components (Figure 3). Its application concerns the analytical process of transforming scientific knowledge into material suitable for teaching. It concerns the way in which the structure of scientific content of a specific field can be transformed into a structure of teaching content for students. Because these two structures are significantly different, the scientific content undergoes an "elemental analysis" to make it accessible to the students but also to enrich it by placing it in context that makes sense to the students. The design and assessment of learning environments refer to the educational material, learning situation and teaching and learning sequences. The design is based on the learning potential of the students on one hand and the clarification of the scientific content on the other (Kattman et al., 1997, Duit, 2005).

3. Method

This work was carried out in the context of the course "Contemporary topics in Physics and their Didactics" of the Master's Program "Didactics in Physics and Educational Technology" of the Department of Physics at the Aristotle University of Thessaloniki. The scientific content for studying the hierarchical structure of the rose petal surface was determined from Bhushan's book on Biomimetics (Bhushan, 2016) as well as Bhushan's and Her's work on fabrication of superhydrophobic surfaces with varying levels of adhesion based on the rose petal behavior. It was also taken into account the two Big Ideas "Size-Dependent Properties" and "Forces and Interactions" of Nano-Science & Nano-Engineering from the book of Stevens et al. (2009).

The didactic transformation of the scientific content was performed following the methodological steps of the MER Model with the aim of developing a learning environment suitable for Upper high-school students and is proposed for a Science club, ie. beyond the scheduled Physics curriculum. The 5E learning cycle was adopted as the instructional design model that defines a learning sequence based on the on the experiential learning philosophy (Bybee et al., 2006).

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

From the scientific content that was presented earlier in the paper, it is easily observed that there are two major axes that the study of the rose petal phenomenon is based upon, the study and characterization of the water droplet and the study of the hierarchical structure. With the help of those two, it is possible to understand the rose petal phenomenon as well as differentiate between two different rose petals based solely upon the difference that is observed in the adhesion and/or wetting. Using the MER model for didactic transformation of the scientific content into content for instruction, and the 5E learning cycle, there have been designed 5 teaching activities.

4.1 The instructional goals

The instructional goals of the teaching activities are the following:

1) To define the rose petal phenomenon
2) To make measurements of the contact angle and the contact angle hysteresis of a water droplet
3) To describe the wetting behaviour of different types of rose petals
4) To differentiate the type of adhesion of two rose petals based on the contact angle hysteresis
5) To predict the wetting model and adhesion of a man-made surface

4.2 The Teaching Activities & the 5E Model

The teaching activities that this work proposes to be utilized in the 5E learning cycle for the rose petal phenomenon are in total four. All activities are designed in order for the students to acquire as much "hands-on" experimentation experience with this phenomenon as nanoscience and the rose petal phenomenon are considered rather intricate and complicated teaching subjects. These four teaching activities are described extensively in the following paragraphs.

The 5E model is implemented in five phases. Those 5 phases are Engage, Explore, Explain, Elaborate and Evaluation. The 5E encompasses the following: Principles Engagement taps student's prior knowledge about a physics concept, Exploration gives students the chance to work with physics concepts in a "hands-on" format. Following the Exploration phases is the Explanation phase, where the teacher and/or students explain the concept in greater detail, introducing students to relevant physics vocabulary. In the Extension phase of the physics lesson, the teacher facilitates deeper or broader understanding of the lesson. Often this phase involves activities that direct students for applying their knowledge to the new situations (Ergin, 2012).

4.2.1 The Engage Phase

Here the task is introduced. Activities aim to spark students' interest and involvement, to engage students into brain-storming activities and to stimulate thinking. An example of such activity is shown in Figure 4. Students are shown with photographs of droplets on different rose petals, and are asked pointed questions (ex. "*what is the shape of the droplets*", "*why does this happen*", "*do you know other leaves with similar behavior*", etc.) to focus the learners' attention on the tasks. The "Engage" phase is concluded students performing experiments on leaves of various plants, dropping water droplets with a pipette and observe the shape of the droplets. The teacher facilitates the process. Questioning, sharing and communication with other learners are encouraged during this phase.


Figure 4: Example of a photo with droplets on a rose petal and students performing experiments on various leaves, for the engage-phase.

4.2.2 The Explore Phase

Learners should take part in activities that allow them to work with materials that give them a 'hands on' experience of the phenomena being observed. A more concise approach to this phase would be the introduction to the first two teaching activities proposed by this work, characterizing the rose petal and characterizing the water droplet. Through these two activities, students should give a more accurate answer to the questions asked by the teacher in the previous phase as well as have a more well-rounded and comprehensive knowledge of the two major parts of the rose petal phenomenon, the surface on which the droplet is set and the droplet itself.

Characterizing the rose petal teaching activity

This activity is focused on the understanding of the behaviour of the rose petal and how the two different rose petals discussed (cv. Bairage and cv. Showtime) have differences in adhesion and wetting as well as the difference between a fresh and a dried rose petal that are observed in the contact angle hysteresis. For this to be achieved, students will be performing hands-on experiments for them to have a more complete idea of the phenomenon and how it operates.

Initially, the students will be given the images of SEM and AFM of the surface of the rose petal in Figure 5 as well as some fresh rose petals of both cv. Bairage and cv. Showtime. Students should be given to understand that despite the fact that visually, the two rose petals have no visible differences when observed with a naked eye, the micro and nanostructure of those two surfaces can vary heavily. It is at this point that is asked from the students to point out the differences using the SEM and AFM images given to them. What we are expecting from the students to observe is the variation in density as well as height of those bumps on each surface.

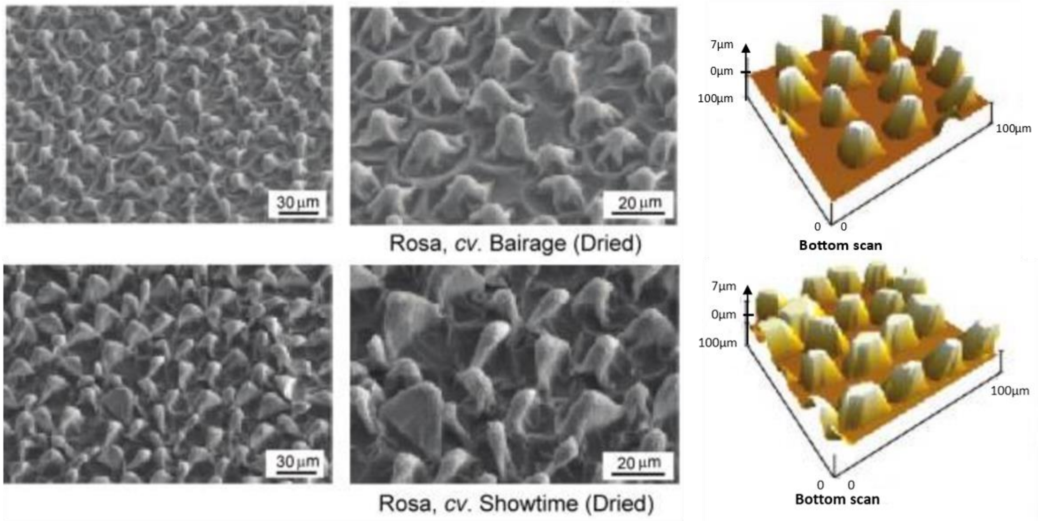

Figure 5. Scanning microscope micrographs and atomic force microscope roughness maps of 2 rose petals, Rosa Hybrid Tea cv. Bairage and Rosa Hybrid Tea cv. Showtime (Bhushan & Her, 2010)

Having seen the different structures of those two rose petals, students will observe with hands-on experimentation in the rose petal phenomenon itself. They will drop one water droplet on the surface of each rose petal that was handed to them and observe the differences. Once this experimentation is over, each student will be handed a dried rose petal and SEM images of a dried and fresh rose petal as well as a schematic of the two overlapping, as seen in Figure 6.

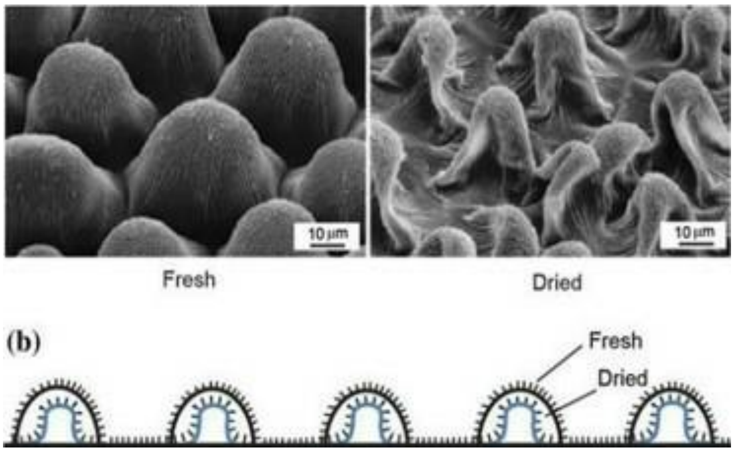

Figure 6. SEM images of a fresh and a dried rose petal (top) and a schematic of the side view of the two rose petals overlapping (bottom) (Bhushan & Her, 2010)

Again, similar to the two separate types of rose petals that the students had to study and point out the differences that they can observe, students are asked to do the same thing with the dried and the fresh rose petal. Also, they will be asked to perform the same experimentation to see whether the rose petal phenomenon will also be observed with the dried rose petal as well as, if there are any differences that are noticeable in the phenomenon itself between the fresh and the dried rose petal. From every single experiment conducted by the students, a photo should be taken on the profile of the water droplet to be used the following teaching activity.

Characterizing the water droplet teaching activity

For the second teaching activity, students will be introduced to the characterization of the water droplet and the two ways that this is possible, the static contact angle and the contact angle hysteresis, as shown in Figure 7.

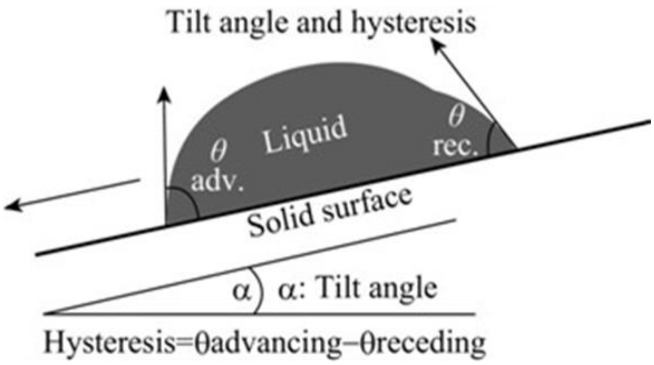

Figure 7. Contact angle hysteresis

For the static contact angle, students will be given photos of different water droplets and will be instructed to measure the contact angle making use of protractors, physical or online (Figure 8). Afterwards, for the measurements of the contact angle hysteresis, the students will use the images they took as well as some others given from the teacher. Students repeat the activity with the droplets in various leaves (Figure 8) inclining the leaves. Utilizing the same online tool and the images taken from the activity, students will be asked to measure the $\theta_{advancing}$ and the $\theta_{receding}$ in order to eventually calculate the contact angle hysteresis on each water droplet.

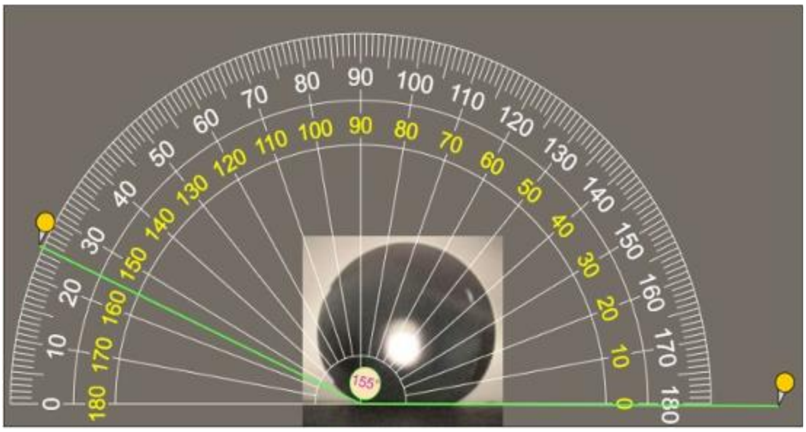

Figure 8. Measurement of the static contact angle using an online protractor

Contact angle hysteresis can be seen as beneficial or detrimental, it is thus crucial to understand it. but there is still a debate about the laws that relate the microscopic picture (pinning on a single defect) to the macroscopic observations (measurement of the hysteresis, which averages on many defects). More generally, we see that the contact angle hysteresis $\Delta\theta = \theta_a - \theta_r$ varies dramatically on a rough solid, from nearly zero to a giant value, of the order of θ_a itself (Quéré, D., 2008).

4.2.3 The Explain Phase

Communication between learners and learner groups can spur the process. The instructor may choose to introduce explanations, definitions, mediate discussions or simply facilitate by helping learners find the words needed. Because of the complexity of the subject to be taught, in this work the role of the teacher needs to be more apparent during the explanation phase, as students might encounter a plethora of difficulties in the third activity, study of the hierarchical structure. Since the study of a micro-nanostructure is probably a foreign concept to most students, the teacher should be wary at all times to help any student having difficulties with either terminology or even fathoming the scale of these things that they are studying.

Study of the hierarchical structure teaching activity

For the teaching activity, being the major factor in the explain phase of the 5E model, students will be introduced to the idea of a micro and a nano-structure and how differences in this hierarchical structure will lead to these surfaces having different wettings models based solely on the difference in the characteristics of each surface. As seen in Figure 9, students will be further acquainted with all the wetting models as well as have a schematic representation of each wetting behaviour, as seen in the microstructure.

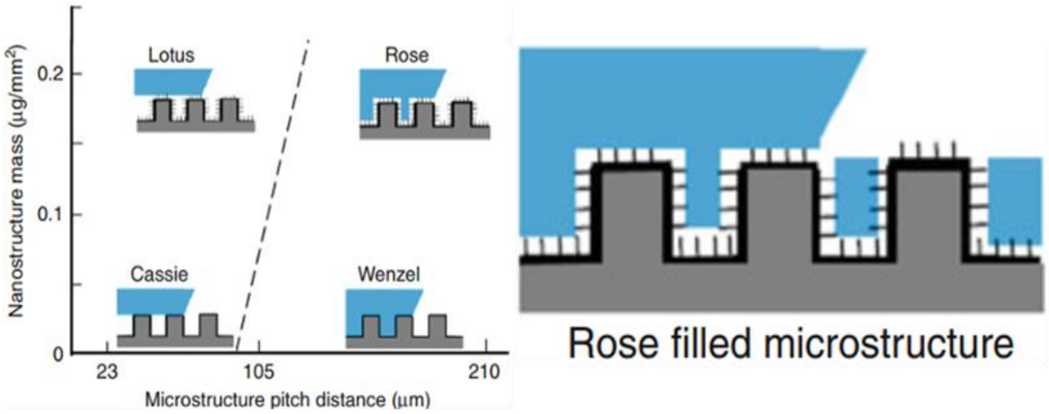

Figure 9. Schematic of a wetting regime map as a function of microstructure pitch and the mass of nanostructure material. The mass of nanostructure materials equal to zero corresponds to microstructure only (Bhushan, 2012)

Furthermore, this teaching activity, being the predecessor of the elaborate phase and the final activity, explains in depth which characteristics of the surface have a role in the different wetting models and how exactly each affects the wetting. This is further reinforced and enhanced with the diagram that is presented in Figure 9.

4.2.4 The Elaborate Phase

Using the understanding gained in the previous stages, now learners should be encouraged build and expand upon it. Inferences, deductions, and hypotheses can be applied to similar or real-world situations. Varied examples and applications of concepts learnt strengthen mental models and provide further insight and understanding. With this idea in mind, the fourth and final teaching activity is utilized in this phase, man-made surfaces mimicking the rose petal phenomenon.

After students have “conquered” these new teaching activities and fully understood the principles that govern the rose petal phenomenon, the concept of Biomimetics is introduced to the students through the study of several man-made surfaces, built in order to present the same behaviour as the surface of the rose petal. Students are getting acquainted with how these surfaces are built as well as how similar their behaviour is to the one of the rose petal.

Man-made surfaces mimicking the rose petal phenomenon teaching activity.

For this activity, students are provided pictures of man-made surfaces designed to mimic the behavior of the rose petal. Based on the characteristics of each surface, similar to the natural surfaces like the rose petal and the lotus flower, students are asked to predict the wetting model that each of these man-made surfaces will present (Figure 10). Based on their prediction of the wetting model, students are going to match a natural surface to each of the man-made surface. Afterwards, students will be given one of each man-made surface in order to experiment with them on the second part of this activity.

Similar to how students experimented by dropping water droplets on the surface of different leaves in the engage phase, students will now execute the same experimental process with the man-made surfaces. After dropping the water droplets on the surface of each man-made surface, students are then asked to take pictures of the profile of the water droplet in order to measure the static contact angle as well as calculate the contact angle hysteresis, in the same way it was done in the second activity (characterizing the water droplet).

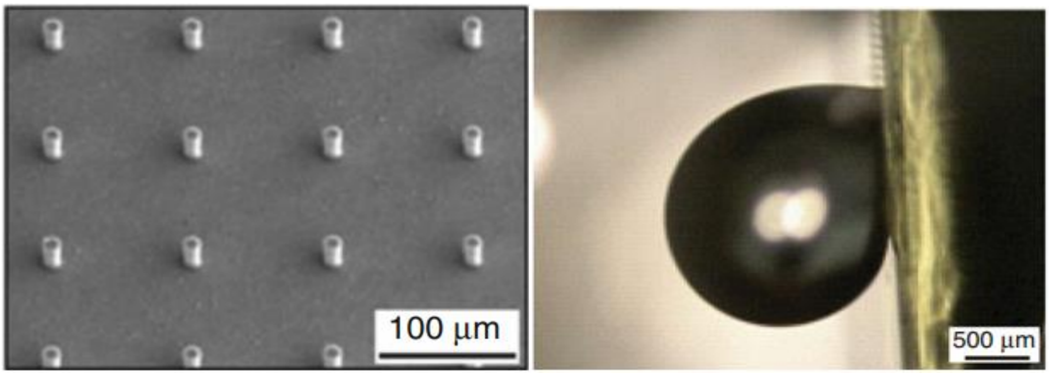

Figure 10. Hierarchical structure of a man-made surface with a 105 μm pitch (Bhushan & Her, 2010)

4.2.5 The Evaluate Phase

Evaluation should be ongoing and should occur at all stages, in order to determine that learning objectives have been met and misconceptions avoided. Any number of rubrics, checklists, interviews, observation or other evaluation tools can be used. If interest in a particular aspect or concept is shown, further inquiry should be encouraged and a new cycle can begin that builds upon the previous one. Inquiries may branch off and inspire new cycles, repeating the process in a spiraling fractal of interrelated concepts, where instruction is both structured and yet open to investigation.

5. Conclusion

The field of Biomimetics provides the scientific community with brand new possibilities for materials and surfaces that are able to mimic with extreme accuracy the behaviour of the natural ones. This also provides educators with a new field of Physics from which they can educationally

PoS(BPU11)257

reconstruct the scientific content into content suitable to be taught to students, with the end goal of students getting more acclimated with the latest updates and adaptations of Physics.

In this work, the scientific content of the rose petal phenomenon was reconstructed with the help of the MER model into being suitable to be taught to High School students. The result of this reconstruction was 5 teaching activities, designed to introduce the students to the phenomenon as well as have them experiment hands-on with the natural surfaces as well as the man-made surfaces designed to mimic the rose petal.

These 5 teaching activities are utilized in the 5E learning cycle, with each teaching activity being designated to be used in one of the 5 stages of the 5E learning cycle (Engage, Explore, Explain, Elaborate, Evaluate). The first 4 activities are targeted into students getting acquainted with the rose petal phenomenon and the science behind it, with the final teaching activity being focused on the man-made surfaces and how well they mimic the natural ones. Therefore, the first teaching activity has a goal to intrigue the students with the subject matter, thus is part of the Engage phase. The second and third teaching activity are part of the Explore phase and with the third activity compromising the Explain phase. The fourth and final activity, being the one discussing and experimenting with the man-made surfaces, is part of the Elaborate phase.

Overall, the five teaching activities along with the utilization of the 5E learning cycle provide a complete cycle of teaching and hands-on experimentation for the rose petal phenomenon, suitable for High School science education. Through this work, students will have “educationally conquered” a rather difficult subject of science as well as be introduced to the more recent developments of science.

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