Interactive Tool Kit for Teaching-Learning Nanoscience and Nanotechnology for High School Students

Nilwala Kottegoda (nilwala@sjp.ac.lk)
University of Sri Jayewardenepura https://orcid.org/0000-0002-9664-1704
Madhavi de Silva
University of Sri Jayewardenepura https://orcid.org/0000-0003-3263-2953
Ajith de Alwis
University of Moratuwa
Chandani Perera
University of Peradeniya
Masilamani Koneswaran
Eastern University Sri Lanka

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Abstract

The broader socioeconomic impact anticipated to occur in the coming decades with the advent of nanoscience and nanotechnology has led many countries to establish national nanotechnology initiatives to promote nanotechnological developments. One major resolution under these mega initiatives is to popularise nanotechnology as a subject at the high school and university levels. However, teaching nanotechnology concepts at the high school level still remains challenging mainly due to the inherent complexity of the associated principles and the unavailability of resourceful talents to teach the subject. Herein, we disclose the development of a nanoscience and nanotechnology educational tool kit for innovative and interactive teaching and learning of nanotechnology at the high school level. This portable tool kit includes several interactive activities such as puzzles and games to understand and visualize nano-scale, synthesis of simple nanomaterials with readily available chemicals, experiments to understand the nano-scale properties, activities to identify nanotechnological effects in nature, and day-to-day life applications in a domestic environment. Several workshops were conducted under the patronage of the National Science Foundation, Sri Lanka to introduce and familiarise this tool kit with both teachers and high school students. The major objective of this design is to multiply the model kit in order to distribute among the school teachers to easily transfer the new field of study to the students by generating interest to extrapolate the theoretical knowledge to real-life situations.

Introduction

Nanoscience/nanotechnology is the science that is involved with the manipulation of matter at either molecular or atomic scale.[1] Nanomaterials are typically considered to be within the range of 1 and 100 nm in size with 1 nm being equivalent to one billionth of a meter (10^{-9} m).[2] This is the magical scale at which most of the biological functions take place and any material scaled down to this size would demonstrate unusual chemical and physical properties due to the quantum effects and high surface area to volume ratios. Even though the word “nano” was not used, this scale was known to scientists for several centuries. For example, the use of carbon nanoparticles to manufacture very strong weapons such as the Damascus sword, incorporating gold nanoparticles to get red or blue color in medieval stained glass, could be stated.[3] Meanwhile, many theoretical concepts were built upon nature's ability to manipulate matter at atomic and molecular scales. However, nanotechnology did not reach the consciousness of scientists until the tools to observe and manipulate matter at the nanoscale were developed in the 1980s. Today nanotechnology has attracted the world’s apprehension in almost every aspect of science and engineering, with implications for ethics, economics, international relations, day-to-day life.[4,5] Its applications have been realized in every field of science and technology including but not limited to medicine, materials, agriculture, energy, environment, etc.[6–10]

Historically, any new science has evolved through an in-depth understanding of the fundamental concepts associated with it. As this happens there is an increased need to effectively passing down the existing knowledge to the succeeding scientists.[11] According to Roco et al, one of the major challenges to the rapid development of the field is the lack of basic education.[5] Therefore, to convey nanoscience and technology in a meaningful way for upcoming scientists, a better understanding of its basic concepts like size, dimensions, history, and day-to-day-life applications at the school level education is imperative. Over the last years, various attempts to develop nano-education-based activities which were mainly focused on experiments to synthesize nanoparticles and introduction of other associated techniques have been reported.[12] However, still there is a paucity of work to familiarise overall basic/fundamental concepts in a student-friendly manner, especially to high school students and to the students in developing regions of the world. It has been emphasized that nanoscience should be taught in an interdisciplinary fashion while introducing courses where practical concerns dictate the teaching attempts.[13] The book titled “The Big Ideas of Nanoscale Science and Engineering” published by the National Science Teacher Association synthesizes that the following nine topics of which size and scale, the structure of matter, forces and interactions, quantum effects, size-dependent properties, self-assembly, tools and instrumentation, models and simulations, nanoscience, technology, and society should be included in the curriculum of K-7 to K-12 levels.[14]

One of the major challenges in incorporating the identified areas into the school curriculum is the development of teaching tools in order to catalyze the students’ conceptualizing ability of the nano-size objects and associated technologies. Blonder and Sakhnini have carried out a detailed study on the subject and found out that the games lead to student engagement, make learning fun, and motivate students and help them to pay attention and stay focused on a subject.[15] There is further evidence that the games allow students to focus and learn better.[16] Paivio has proposed that the visual and auditory approaches motivate students to learn and understand a subject more clearly.[17] Previous studies in nano-education have outlined the importance of the use of visualization tools and hands-on-experiences in teaching nanoscience and technology to generate interest and clear understanding about the subject among middle and high school students.[18] One of the best methods proposed for teaching nanotechnology is project-based learning which is a comprehensive perspective that focuses on teaching by engaging students in investigation. On the other hand, project-based learning places students in realistic, contextualized problem-solving environments. In this quest, a few nano-educational products developed by Nanoscale Informal STEM Education Network (https://www.nisenet.org/nano)[19] and “Exploring the Nanoworld” activity kit introduced by the Institute for Chemical Education[20] could be mentioned. Overall, interactive activities such as games, hands-on-experiences, project-based learning lead to improved communication between teachers and students. Such activities which improve communications are known to be successful in effective learning and understanding of the subject allowing students to achieve better grades.[21]

However, there has been no successful attempt thus far to develop interactive teaching tools to teach and learn basic concepts of nanotechnology in secondary schools particularly in developing countries where the majority of the world’s students are concentrated and struggling with limitations to access to online resources and availability of activity/toolkits.[22] In order to fill in this void, the current work attempts to develop a portable low-cost tool kit to teach-learn nanoscience and nanotechnology for high school students. This tool kit has been developed by consolidating familiar concepts that students come across in their daily lives with various types of highly interactive activities. Due to its low production cost and easy-to-understand nature, this tool kit could be fruitfully introduced to schools and institutes including those coming from low-income areas and thus leading to the introduction of the latest nanoscience and nanotechnology concepts to underrepresented communities in science.

Methodology

The Nanoscience and Technology Teaching-Learning Tool Kit consists of the following subsets; activities to understand and visualize nanoscale and nanotechnology, a model nano-laboratory that demonstrates the real-world applications of nanotechnology, simple experiments that help students to synthesize nanomaterials, nanotechnology model building activity, and nanotechnology in nature activity. Each subset comprises games and models to demonstrate the basic concepts of nanotechnology.

Dimensions of the nanoscience and nanotechnology teaching-learning toolkit:

The nanoscience and technology toolkit was developed as a portable, easy-to-handle, low-weight toolkit. See Table 1 for the dimensions of the toolkit.

Table 1
Dimensions of the nanoscience and nanotechnology toolkit

Item	Length (cm)	Width (cm)	Height (cm)	Weight (g)
Rubik’s Cube	5.7	5.7	5.7	80
Nano Card Pack	6.2	8.8	-	65
Word Puzzle	30	30	-	4.5
Board Game	25.4	25.4	-	3.2
Nanohome	45	40	30	1350
BuckyBall Template	15	15	-	1
Carbon Nanotube Puzzle	10	10	-	20
Nano-experiment kit	15	20	12	250
User Guide	21	29.7	2	110
Total				1883.7

1. Activities to understand and visualize the nano-size:

The tool kit has been designed in order to impart an understanding of the size scale and how the surface area to volume ratio changes with size, which is the fundamental concept behind nanoscience. As stated before, objects and concepts at the nanoscale are hard to visualize, difficult to describe, abstract, and their relationships to the observable world can be counter-intuitive.

a. Simple activities to understand the nano-scale:

I. Measuring the diameter of human hair:

Students are provided with an electron microscopic image of a human hair with the exact size scale. They measure the diameter of a human hair using a measuring ruler and compare the nanometer scale to their measurement. Here, they will learn the conversion between different size scales.

II. Increase of surface area to volume ratio at the nanolevel:

Students are provided with a large cube containing detachable cubes. Using the real-time measurements students will construct the surface area/volume ratio vs particle size curve to understand the noticeable change in the surface area/volume ratio at the magic point of 100 nm.

b. What is the nanometer scale? - Rubik's cube activity:

As one of the first steps in introducing nanotechnology concepts to students, an activity based on a Rubik's cube (Fig. 1) is included. After completing the activity students will have a clear understanding of 'how to classify the things in the real world based on their size' ultimately leading them to a fundamental understanding of the size scale of a 'nanometer'. The Rubik's cube contains pictures of macro, micro, nano and atomic-scale objects, and their dimensions. Students will organize the cube to get similar scale objects together to one face. This exercise will train the students to visualize and familiarise themselves with the size scale by taking them through an interesting journey of playing a brain-teasing game.

c. Nano Card Pack:

Students are provided with 32 cards (Fig. 2) containing information about synthetic and natural nanomaterials, their applications, properties, and important events and people in the development of nanotechnology. Each team has 6 players and they should match the nanoparticle to its properties and applications or the important historical events to the person and his image.

d. Nano Word puzzle:

Interactive word puzzle (Fig. 3) that helps to familiarise with the terminology, natural concepts, history, and applications of nanotechnology. Students have to circle the right answer for each of the questions by spotting the correct answer on the puzzle.

e. Nano Board Game:

A board game that is inspired by the "Snake and Ladder" board game was created for students in order to get an idea of the objects in the nanoworld, micro world, and macro world. The basic principle of surface area to volume ratio increases when something goes to the nano level underlay throughout this game. Micro and macro objects are placed in the faces of the snakes and the ladders start with the nano-objects (Fig. 4). The rules of the game are similar to that of a typical snake and ladder game.

2. A model nano-laboratory which demonstrate the real-world applications of nanotechnology:

This teaching-learning aid, a nano-laboratory is designed as a portable and detachable kit where the teacher can demonstrate the activities easily and in an interactive manner. This teaching-learning aid has been constructed by a 3-D printing technique where layer by layer assembling leads to the formation of the 3-D structure, See Fig. 5.

The following concepts are demonstrated in the toolbox:

- The outer box is made using 3-D printing techniques using polypropylene
- The nano-laboratory contains the following items

1. Roof Top contents (see Fig. 6)

- A rooftop equipped with a garden that uses smart fertilizer and seed coatings
- A swimming pool that is self-cleaning: Students could visualize the lotus effect and dust-free nature of the pool.
- Nano TiO2-based solar cell – concept has introduced

- A car with self-cleaning paint

2. Inside the laboratory (see Fig. 8)

Demonstration samples (Fig. 7) of

- Optical nanoparticles – Au and Ag
- Carbon-based nanomaterials - CNT
- Superhydrophobic nanoparticles – Silica
- Photocatalytic nanoparticles – ZnO and TiO_2
- Ferromagnetic nanomaterials – Fe_3O_4
- Industrially important natural minerals useful for the production of nanomaterials are demonstrated.

Applications of nanotechnology

- Homemade water filter containing coconut coir based activated carbon (Fig. 9)
- A lady scientist wearing a self-cleaning lab coat
- A first aid box containing homemade clay-curcumin encapsulated antibacterial cream
- Replicas of slow-release drugs (Fig. 9)
- Nanotechnology-based cosmetics (Fig. 9)
- A locally produced dye-sensitized solar-cell is fixed into the roof and used to light an LED bulb

Figure 9: Nano cosmetics, First-Aid box with Nanomedicine, Nano water filter

3. Natural nano-concepts

- Lotus effect
- Spider web

4. History of nanotechnology

- Important contributions of the scientists has been explained pictorially on the walls (Fig. 10)

3. Simple experiments that help students to synthesize nanomaterials:

This tool kit is equipped with a number of experiments that offer hands-on experiences to students. Few of these experiments are adapted from recent publications in nanotechnology (Author, 2017; Author, 2020; Author, 2014; Author, 2018). Materials needed for each of the experiments together with the instructions are provided in the toolkit. Most of the experiments are designed to demonstrate the possibility of using locally available materials to synthesize advanced nanostructures and to understand their properties.

i. Size dependence of light scattering properties - Tyndall experiment:

Students are provided with a colloidal dispersion (milk), ionic solution (kitchen salt), and a nano-dispersion. The scattering pattern of a laser beam through the solution is studied. Students understand how the interaction between laser light and the particles provides approximate information on the particle size.

ii. Graphene circuit:

Students are guided to design an electric circuit using a dark pencil line to complete the pathway. A thin pencil line consists of several layers of graphene (0.5 nm thick layers) and it has a high electric conductivity. This experiment demonstrates even a few layers of graphene is sufficient to create an electric circuit thus students understand that electric properties are enhanced when the nano-level is reached (https://www.nisenet.org/nano)

iii. Liquid magnet:

Fe^{2+}/Fe^{3+} solution and other materials needed to make a ferrofluid are provided as a demonstration pack. Students synthesize iron oxide nanoparticles dispersion and initially observe how agglomeration of particles occurs. Then, the surface modifies the particles in order to stabilize the synthesized nanoparticles. Magnetic behavior is studied using a simple magnet.

iv. Synthesis of gold nanoparticles:

Students are provided with a gold/silver salt and other ingredients needed to synthesize nanoparticles. By changing the synthesis parameters students synthesize the rainbow colors of nanomaterials. These experiments explain the change in optical properties with size.

v. Synthesis of urea-hydroxyapatite nanohybrids:

The chemicals and reagents needed to synthesize Urea-Hydroxyapatite hybrids are provided to students. They are asked to synthesize hydroxyapatite nanoparticles first and then move into synthesizing Urea-Hydroxyapatite nanohybrids. This will give students a clearer idea of how to derive hybrids based on nanoparticles. After the completion of the experiment, students are asked to find more examples of other nanohybrids that have been developed by scientists.

4. Nanotechnology model building activity:

a. Let’s make a buckyball:

Students get hands-on experience to make a buckyball using a simple schematic diagram. A printed template is given to the students where they can cut the hexagons and arrange it to form the buckyball. The teacher will give the basic introduction on the steps to build the buckyball and in the template, the way students should start building it is marked with numbers.

b. Let’s make a carbon nanotube:

Students are provided with a 30-piece 3D printed puzzle purchased commercially. When they complete the puzzle students will get to see an image of a carbon nanotube as the end result.

5. Nanotechnology in nature activity:

Students are instructed to explore the instances where nanotechnological effects could be seen in nature.

a. Nanotechnology in plants: Lotus leaf effect activity

A lotus leaf is given to students and they are asked to drop water on the surface of the leaf with the use of a dropper/spatula (Fig. 11). Each student should tell the teacher their observation. After the activity teacher will explain the nanotechnological concepts behind the lotus leaf effect.

b. Nanotechnology in Animals: Gecko and spider web effect

The teacher is provided with Scanning Electron Micrograph images of gecko hands and a spider web. These images should be displayed to students and teachers should try to get the answers from students by asking appropriate questions and raising their curiosity. Then the teacher will explain the basic nanotechnological concepts behind these effects.

The teaching-learning toolkit is equipped with a CD and a user manual in the native language, Sinhala and English.

Deployment of the nanoscience and nanotechnology teaching-learning toolkit:

In order to investigate the teachers’ and students’ responses to this nanoscience and nanotechnology toolkit, 25 + workshops/seminars were conducted in schools for high school students under the patronage of the National Science Foundation, Sri Lanka. Teachers and students were given hands-on-experience in teaching and learning nanotechnology using this toolkit.

Discussion

Each subset included in the Nanoscience and Technology Teaching-Learning Tool kit has designated learning outcomes at the end of completing each activity. Teachers can use these parameters to check whether the students comprehend and grasp the concepts after engaging in the activities.

1. Learning Objectives of the activities to understand and visualize the nano-size:

At the end of activities, students should be able to

1. Explain the nano-scale with suitable unit conversions
2. Identify the appropriate scale to explain the size of a given object
3. Precisely define nanometer-scale
4. Explain the properties of various nanomaterials and map their applications
5. Describe the historical events significant to the nanotechnology developments
6. Explain the natural nanotechnology-based concepts
7. Identify the current applications of nanotechnology

2. Learning Objectives of the model nano-home:

At the end of this demonstration, students are able to

1. Describe the real-world applications of nanomaterials in detail
2. Get hands-on experiences with the functioning mechanism of nano-enabled products
3. Touch and feel the functions of nano-products
4. Discuss the properties of nanomaterials
5. Identify examples for nanomaterials that give specific properties
6. Explain the size-dependent optical properties of Au and Ag nanoparticles.
7. Select the suitable nanomaterials for a given industrial application
8. Discuss the availability of a range of natural minerals suitable for nanoparticle production
9. List the examples of locally available minerals that have commercial potential
10. Discuss the important historical events and important scientific contributions to the development of nanotechnology
11. List and discuss the nanotechnology involvement in some natural concepts
12. Discuss the working principle of an atomic force microscope

3. Learning Objectives of the simple experiments synthesize nanomaterials:

At the end of this demonstration, students are able to

1. Synthesize some economically relevant nanomaterials
2. Explain the properties of these nanomaterials
3. Get hands-on experiences on how to test the unique properties of the selected nanomaterials
4. Explain why stabilization of nanoparticles is important
5. Select suitable methods for stabilization of nanoparticles

4. Learning Objectives of the nanotechnology model building activity:

At the end of the activity, students should be capable of

1. Get hands-on experiences to build up the models of carbon-based nanomaterials.
2. Explain the structural features of nanomaterials.

5. Learning Objectives of the nanotechnology in nature activity:

At the end of the activity, students should be capable to

1. Identify nanotechnological effects in nature
2. Explain the nanotechnological concepts behind those natural effects
3. Explain how scientists got inspired by what they saw in nature.
4. List out examples of nanotechnology applications inspired by nature.

Conclusions

This portable nanoscience and nanotechnology teaching-learning tool kit allow high school students to interactively engage in the learning process of nanoscience and technology while facilitating the teacher's efforts to deliver the subject matters effectively to students. The broader nanoscience and nanotechnology concepts are made simpler to students by introducing those concepts through hands-on-activities and games with the aid of visualization tools and materials which are readily available. As this tool kit uses many day-to-day life examples, students will be capable of relating what they observe and experience in real life to nanotechnological concepts. Teachers can monitor the progress of knowledge of students after using the tool kit by evaluating them based on the learning outcomes mentioned. Since the production cost of this tool kit is low it can be used by teachers around the world even in low-income countries. The development of this interactive nanoscience and technology tool kit has opened up new learning opportunities not only for high school teachers but also for respective students as well.

Declarations

Competing interests: The authors declare no competing interests.

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Figure Legends

Figure 1: Rubik's cube activity to understand the size scales; Students should arrange the macro, micro, nano and atomic size scale objects to one common face in the cube.

Figure 2: Card pack containing the information about nanoscience and nanotechnology

Figure 3: Interactive nano-word puzzle

Figure 4. Snake and Ladder inspired board game.

Figure 5. Nano-laboratory structure (The content and the roof are detachable).

Figure 6. Rooftop of the Nano-laboratory.

Figure 7. The collection of nanoparticles inside the laboratory.

Figure 8. The complete look of the inside of the nano-laboratory

Figure 9. Nano cosmetics, First-Aid box with Nanomedicine, Nano water filter.

Figure 10. A wall of the nano-laboratory containing pictures of scientists who contributed to the development of nanoscience and technology.

Figure 11. Student trying out the lotus effect activity.

Figures

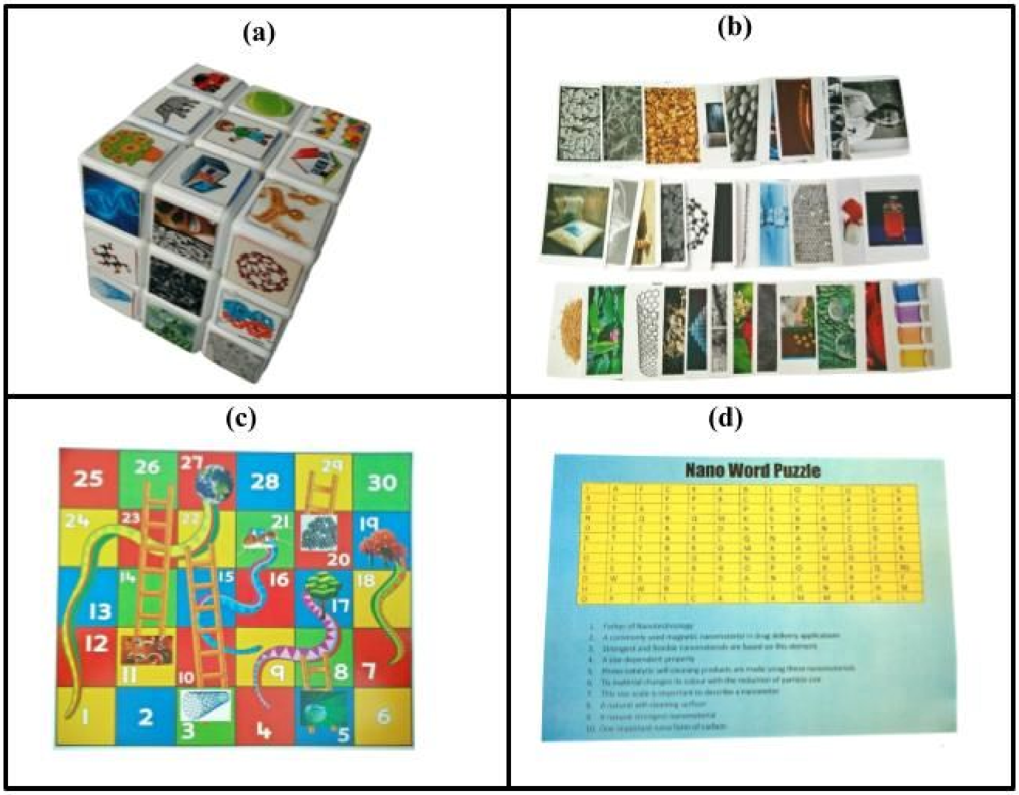

Figure 1

(a) Rubik’s cube activity to understand the size scales (b) Card pack containing the information about nanoscience and nanotechnology (c) Interactive nano-word puzzle, (d) Snake and Ladder inspired board game

Figure 2

Nano-laboratory structure (The content and the roof are detachable)

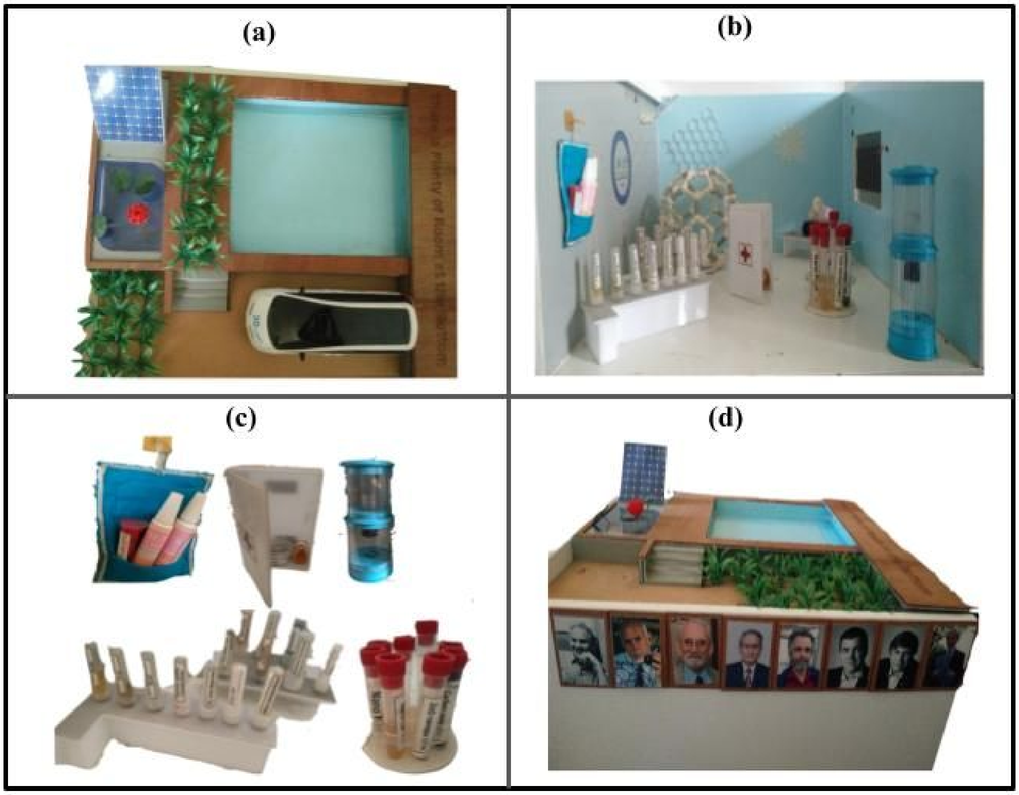

Figure 3

(a) Rooftop of the Nano-laboratory, (b) The complete look of the inside of nano-laboratory, (c) Top Row (left to right): Nano cosmetics, First-Aid box with Nanomedicine, Nano water filter, Bottom Row: The collection of nanoparticles inside the laboratory, (d) A wall of the nano-laboratory containing pictures of scientists who contributed to the development of nanoscience and nanotechnology

Figure 4

Figure 11: Student trying out the lotus effect activity