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Full Length Research Paper

Studies on structural, surface morphology and optical properties of Zinc sulphide (ZnS) thin films prepared by chemical bath deposition

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Zinc sulphide (ZnS) thin films have been prepared by chemical bath deposition method. X-ray diffraction (XRD) is used to analyze the structure and crystallite size and scanning electron microscopy is used to study the particle size and morphology of ZnS thin film. Optical studies have been carried out using UV-Visible-NIR absorbance spectrum. The band gap value of the film is calculated and it is found to be 3.45 eV. The dielectric properties of ZnS thin films have been studied in the different frequency at different temperatures.

Key words: Zinc sulphide (ZnS) thin films, X-ray diffraction (XRD), scanning electron microscopy (SEM), dielectric studies.

INTRODUCTION

Zinc Sulphide (ZnS) belongs to II-VI group compound with wide direct band gap value ranging from 3.4 to 3.70 eV. Zinc sulfide has cubic or hexagonal crystal structure or both at the same time. ZnS has significant potential applications such as in antireflection coating for light emitting diode (Katayama et al., 1975) for heterojunction solar cells (Bloss et al., 1988) and other optoelectronic devices such as electro luminescence devices and photovoltaic cells which are used in the field of displays (Beard et al., 2002), blue light emitting diode (Coe et al., 2002) sensors and lasers (Klimov et al., 2000) etc. In recent years nanocrystalline ZnS attracts much consideration because the properties in nano form vary significantly from those of their bulk.

Therefore, effort has been made to control the size, morphology and crystallinity of ZnS thin film in a wide variety of applications (Mach and Mueller, 1991; Varitimos and Tustison, 1987). ZnS thin films have been prepared by various methods such as thermal evaporation (Dimitrova, 2000), spray pyrolysis (Mustafa et al., 2007), sputtering (Shao et al., 2003), chemical vapor deposition (Icimura et al., 1999), successive ionic layer adsorption and reaction (Nomura et al., 1995), and metal organic vapour phase epitaxy (MOVPE) (Roy et al., 2006). In the present investigation, we report the synthesis and characterization of ZnS thin films. The ZnS thin films were characterized by X-ray diffraction, and scanning electron microscopy (SEM), for microstructure

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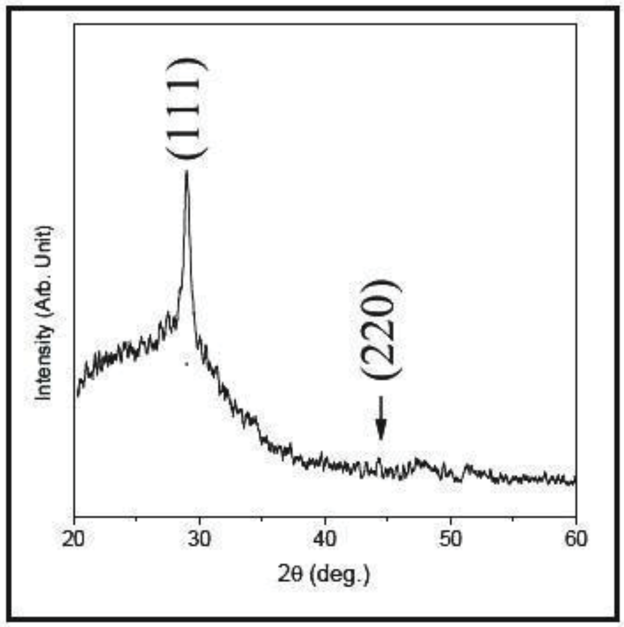

Figure 1. XRD spectrum of ZnS thin films.

and morphology respectively, while UV-VIS-NIR analysis and dielectric for optical studies.

EXPERIMENTAL PROCEDURE

The preparation of ZnS thin films is based on the chemical bath deposition method which was carried out by dissolving zinc acetate and thiourea in double distilled water and at the deposition temperature of 60°C. Then, Ammonia solution was added slowly with constant stirring to form the complex and pH of 10 was achieved. The deposition was done by keeping the substrates vertically inside the chemical bath. Deposition time of five minutes was recorded and the films were rinsed in double distilled water and then dried in air atmosphere. The X-ray diffraction (XRD) pattern of the ZnS thin films was recorded by using a powder X-ray diffractometer (Schimadzu model: XRD 6000 using CuKα (λ=0.154 nm) radiation, with a diffraction angle between 20 and 60°. The crystallite size was determined from the broadenings of corresponding X-ray spectral peaks by using Debye Scherrer's formula. Scanning electron microscopy (SEM) studies were carried out on JEOL, JSM- 67001. The optical absorption spectrum of the ZnS thin films has been taken by using the VARIAN CARY MODEL 5000 spectrophotometer in the wavelength range of 300 to 600 nm. The dielectric properties of the ZnS thin films were analyzed using a HIOKI 3532-50 LCR HITESTER over the frequency range 50Hz-5MHz.

RESULTS AND DISCUSSION

X- ray diffraction analysis

Structural identification of ZnS films has been done using with X-ray diffraction in the range of angle 2θ between 20° to 60° as shown in Figure 1. The excellent peaks (111) and (220) have been obtained. This film shows reflection along (111), (220) peaks corresponding to formation of hexagonal structure of ZnS. The broadened peak shows the nanometer-sized crystallites. The average nano-crystalline size (D) was calculated using the Debye-Scherrer formula:

$$D = \frac{0.9\lambda}{\beta \cos\theta} \qquad (1)$$

where λ is the X-ray wavelength (CuKα radiation and equals to 0.154 nm), θ is the Bragg diffraction angle, and β is the FWHM of the XRD peak appearing at the diffraction angle θ. The average crystalline size is calculated from X-ray line broadening using (111) peak and Debye-Scherrer equation to be about 16.4 nm.

Scanning electron microscope (SEM)

Scanning electron microscope (SEM) was used for the study of surface structure and roughness of the ZnS thin films. Figure 2 shows the SEM images of the ZnS thin films. The spherical crystallites which have the mean particle size of ~ 12 nm are visible through the SEM analysis.

UV-VIS-NIR spectral analysis

Study of materials by means of optical absorption provides a simple method for explaining some features concerning the band structure of materials. The optical absorption spectrum of ZnS films has been recorded in the wavelength region 300 – 600 nm and it is shown in Figure 3. It is important to note that ZnS films were highly transparent in the visible region. The absorption edge has been obtained at a shorter wavelength. The broadening of the absorption spectrum could be due to the quantum confinement of the ZnS thin films. As it is clear from spectrum, the films have a steep optical absorption feature, indicating good homogeneity in the shape and size of the nano-crystallines and low defect density near the band edge. Generally, the wavelength of the maximum exciton absorption decreases as the particle size decreases, as a result of the quantum confinement of the photo generated electron–hole pairs. The blue shift in the absorption spectrum is mainly attributed to the confinement of charge carriers in the nanoparticles. The dependence of optical absorption coefficient on photon energy helps to study the band structure and type of transition of electrons.

The optical absorption coefficient (α) was calculated from transmittance using the following relation:

$$\alpha = \frac{1}{d}\log\left(\frac{1}{T}\right) \qquad (2)$$

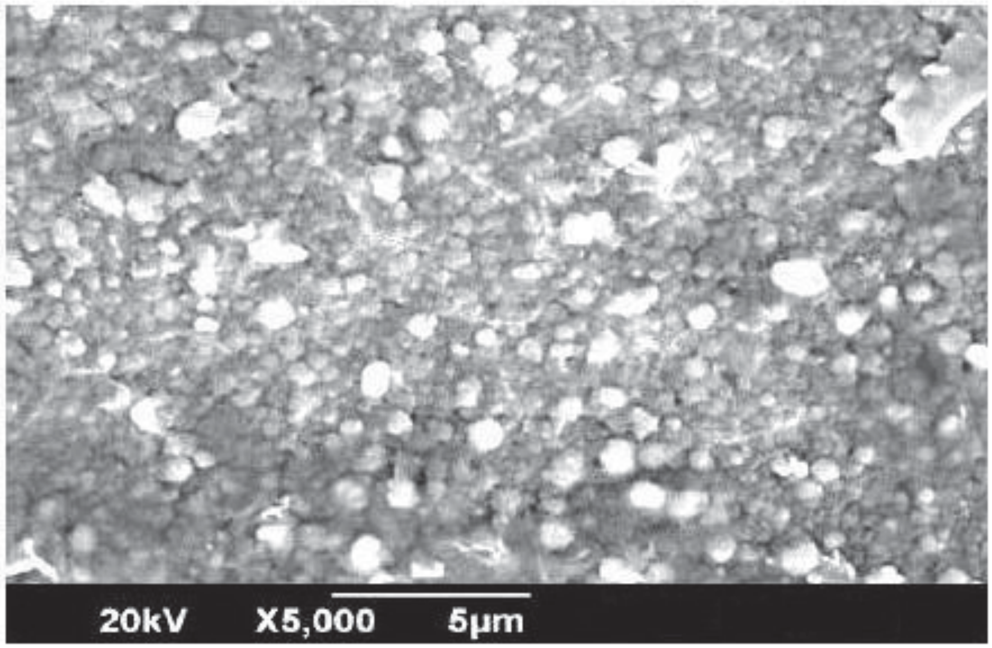

Figure 2. SEM Image of the ZnS thin films.

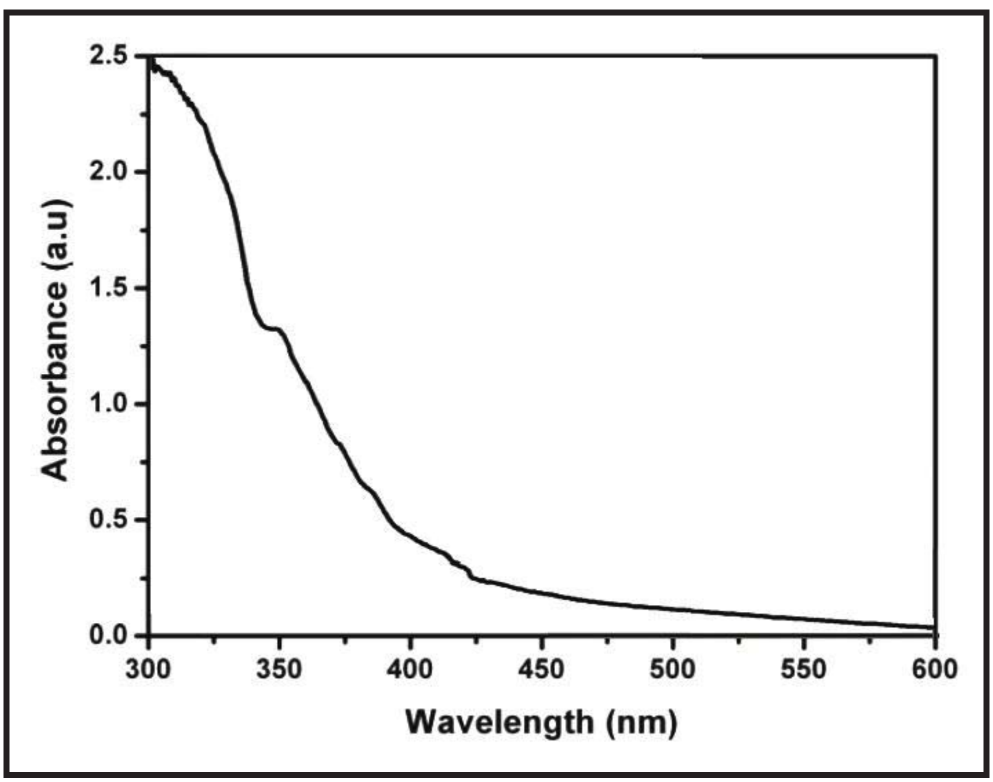

Figure 3. UV-Vis absorbance spectrum of ZnS films.

where T is the transmittance and d is the thickness of the film. As a direct band gap material, the film under study has an absorption coefficient (α) obeying the following relation for high photon energies (hν):

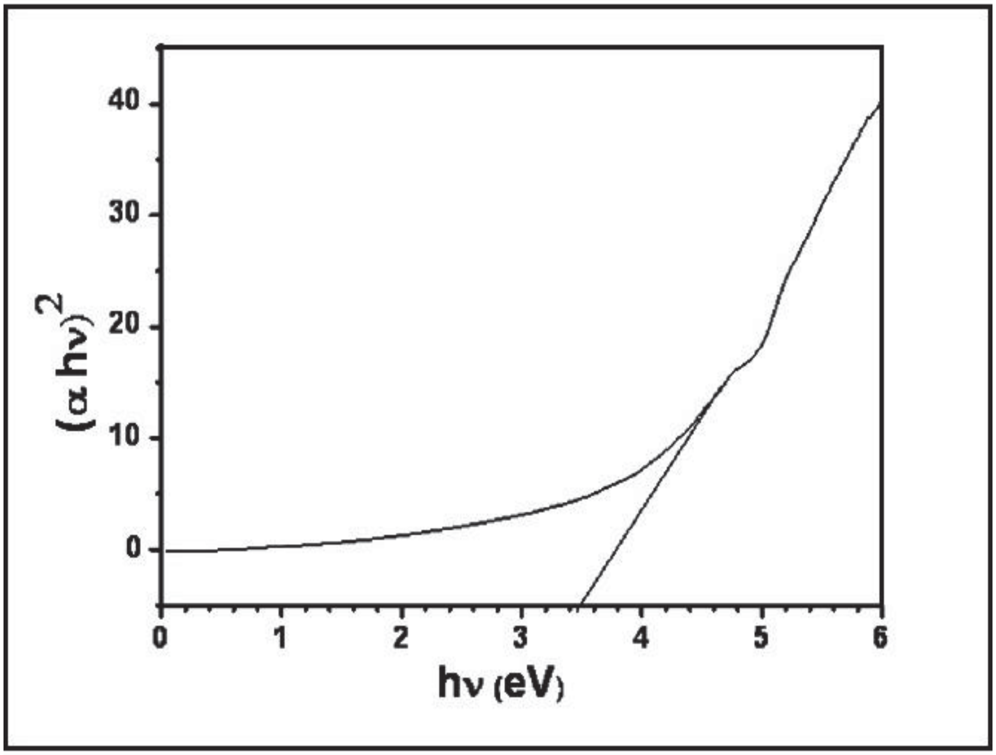

Figure 4. Plot of $(\alpha h\nu)^2$ Vs photon energy.

$$\alpha = \frac{A(h\nu - E_g)^{1/2}}{h\nu} \tag{3}$$

where E_g is the band gap of the ZnS films and A is a constant. A plot of variation of $(\alpha h\nu)^2$ versus hν is shown in Figure 4. Using Tauc's plot, the energy gap (E_g) is found to be 3.50 eV which agrees well with the reported values (Shinde et al., 2011). The energy absorption gap is of direct type and the large band gap clearly indicates the wide transparency of the film. The result could be attributed to the quantum size effects as expected from the nanocrystalline nature of the ZnS thin films.

Dielectric properties

The dielectric properties of the ZnS thin films have been measured at different frequency and temperatures. The dielectric constant has been calculated with frequency at different temperatures as shown in Figure 5, whereas the following dielectric losses are depicted in Figure 6. Figure 5 showed that the dielectric constant decreases exponentially with increasing frequency and then reaches almost a constant value in the high frequency region. This also shows that the value of the dielectric constant increases with an increase in the temperatures. The large value of the dielectric constant is owing to the fact that ZnS thin films acts as a nanodipole under electric fields. The small-sized particles need a large number of particles per unit volume, ensuring increase of the dipole moment per unit volume, and a high dielectric constant (Suresh and Arunseshan, 2014). The decrease in the dielectric constant is due to electronic polarization which is quite less. Dipolar polarization is also expected to decrease with temperature as it is inversely proportional to temperature (Suresh, 2014). The polarizability of the space charge depends on the purity of the nanoparticles. As the temperature increases, the space charge effect towards polarization may have a tendency to increase (Sagadevan, and Sundaram, 2014). In Figure 6, the curves show that the dielectric loss is dependent on the frequency of the applied field, comparable to that of the dielectric constant. The dielectric loss decreases with an increase in the frequency at almost all temperatures, but appears to achieve saturation in the higher frequency range at all the temperatures (Sagadevan and Murugasen, 2014).

Conclusion

The Zinc sulphide (ZnS) thin films have been prepared by chemical bath deposition technique. Structural and morphology of the ZnS thin films were investigated by XRD and SEM. The XRD studies show the well crystallized

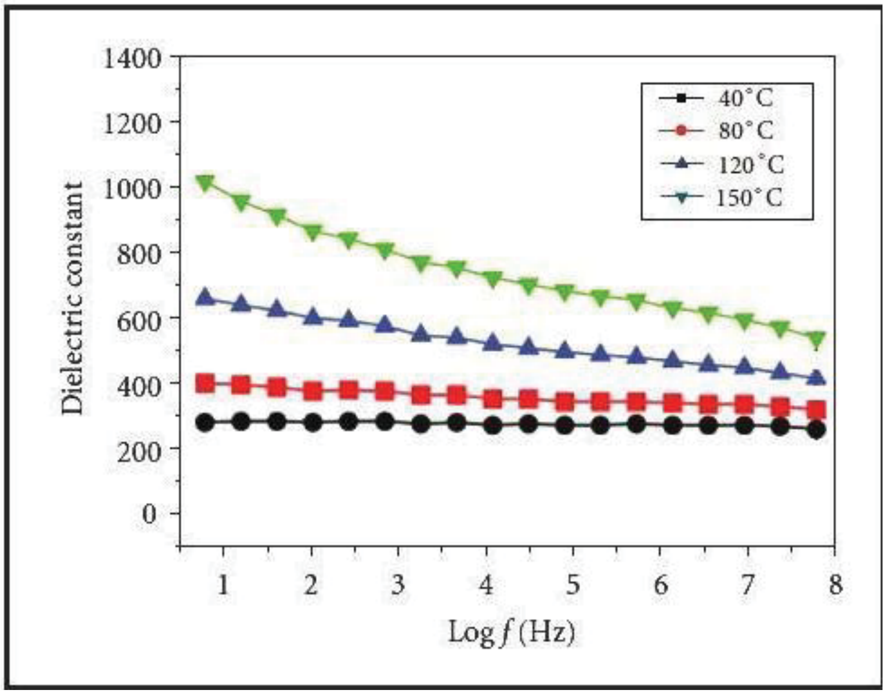

Figure 5. Dielectric constant of ZnS thin films.

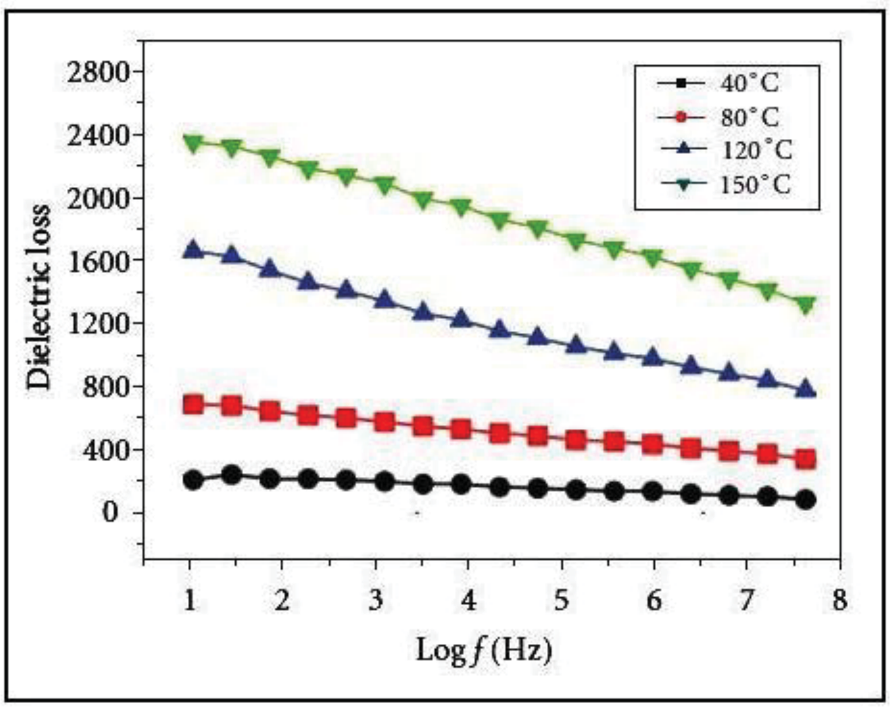

Figure 6. Dielectric loss of ZnS thin films, as a function of frequency.

and cubic structure of ZnS thin films. The UV-Visible absorbance spectrum shows excellent transmission in the entire visible region. The optical band gap is found to be 3.45 eV. The dielectric constant and dielectric loss of the ZnS thin films are calculated in the different frequency and temperatures.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Soil carbon storage in dominant species of Mangrove Forest of Sarawak, Malaysia

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Carbon storage in forest ecosystems involves inordinate components including plant biomass carbon and soil carbon. Sequestration of carbon along with other aggressive conservation efforts helps to reduce the increasing negative impact of global warming on the environment and mangroves as the coastal forest. The objective of this study was to assess the soil carbon storage of dominant plant species of Awat-Awat Mangrove Forest, Sarawak, Malaysia. A total of 32 soil samples of mangrove forest were collected in nine different plots with different species using a peat auger at a soil depth of 0 to 50 cm. The total C in the soil samples was analyzed using CHNS analyzer (TruSpec Micro Elemental Analyzer (NCHS), LECO, USA). Soil carbon content of mangrove forest was found varies in each plot. The highest soil carbon content in Awat-Awat Mangrove Forest was found for soil under dominance of *Rhizophora mucronata* (6.24%) whereas the lowest (1.73%) was found for soil under dominated by *Sonneratia alba*. The soil carbon content of Awat-Awat Mangrove Forest was found to be influenced by the difference in species dominance.

Key words: Soil carbon storage, soil carbon, species dominance, mangrove forest, Sarawak, Malaysia.

INTRODUCTION

Among all of source of life on the earth, carbon is one of the primary one. It is found in all living organism and obtainable in many forms, mostly as tree biomass, soil organic matter and as gasses (CO_2) in the atmosphere. Carbon is also the major component of soil organic matter, but its content can vary from 48 to 60% or more of the weight of soil organic matter (Tan, 2005). Carbon sequestration is the carbon that is stored in long term which is available in the oceans, soils, vegetation (especially forests), and geologic formation (ESA, 2000). Carbon storage in forest ecosystems involves inordinate components including biomass carbon and soil carbon (Lal, 2005). Along with soil properties such as soil chemical properties, it can indicate the current status and also determine the characteristics of tested mangroves soil. In addition, soil carbon contain approximately 75% of

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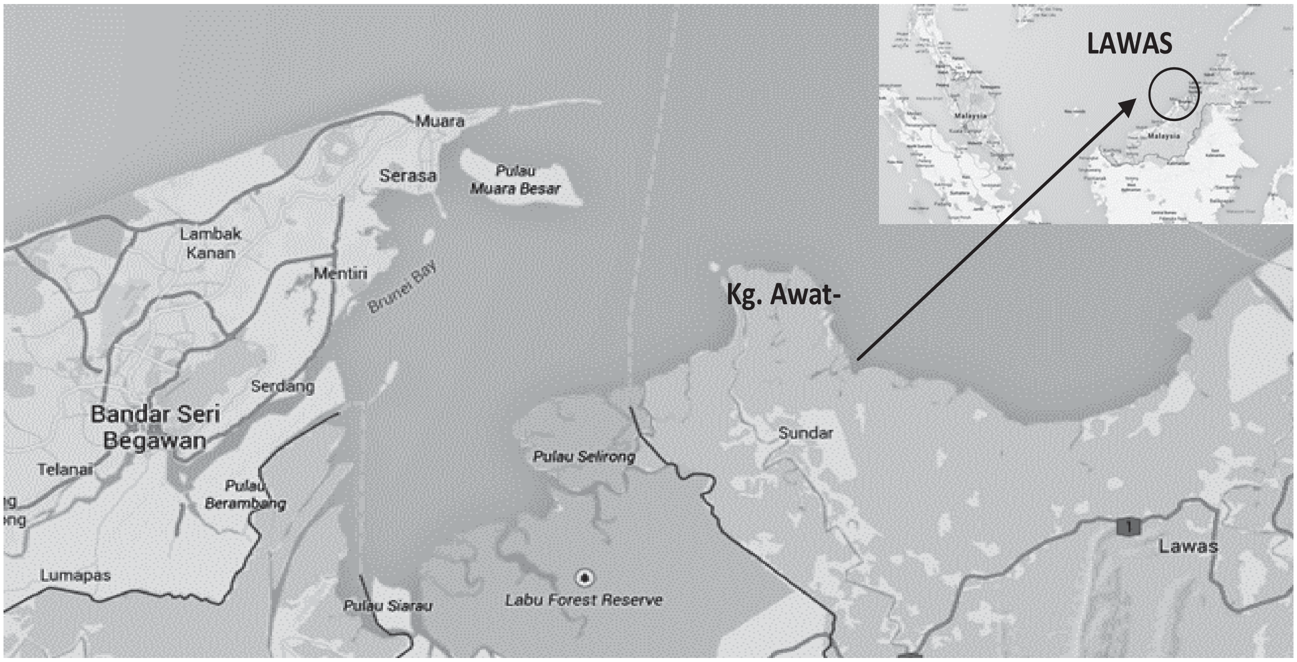

Figure 1. Location of study area at Awat- Awat Mangrove Forest in Lawas, Sarawak, Malaysia.

the carbon pool on land and it is three times more than the number of carbon stored in living plants and animal (ESA, 2000; Lal, 2005).

Sequestration of carbon along with other aggressive conservation efforts helps to mitigate the increasing negative impact of global warming on the environment and mangroves as the coastal forest. Sequestration of carbon also plays significant role in the global carbon cycling because they store a large stock of carbon as well as potential carbon sinks and sources to the atmosphere (Muukonen and Heiskanen, 2007). Moreover, in the last decade, strong evidence about significant differences among mangrove soils due to the presence of different mangrove species has been reported (Lacerda et al., 1995). The different among those mangrove soils might be determined from mangrove species composition which is different in each zone of mangrove forest. Furthermore, the main objective of this study was to assess the soil carbon storage of dominant plant species of Awat-Awat Mangrove Forest, Sarawak, Malaysia (Figure 1).

MATERIALS AND METHODS

This study was carried out in Awat-Awat Mangrove Forest, Lawas Sarawak, Malaysia, 4°56'N, 115°14'E. Nine plots were established in each area with different dominant species. Moreover, *Rhizophora apiculata* Blume is the main species of Awat-Awat Mangrove Forest, Lawas, Sarawak, Malaysia (Chandra et al., 2011). Soil sampling was done in November 2012. Soil samples were collected randomly in every plot using a peat auger at a depth of 0 to 20 cm and 20 to 40 cm depth and a total of 42 samples were collected during this study period. The soil samples were placed into closed labeled plastic bag and transported to UPMKB soil laboratory for processing. Samples were air dried at room temperature, ground and sieved pass to 0.05 mm for further analysis. Soil pH from each plot was determined use the potentiometric method of Tan (2005). The total C content of soil samples was analyzed using CHNS analyzer (TruSpec Micro Elemental Analyzer (NCHS), LECO, USA). The soil organic matter was determined using the conversion factor 1.724 that has been used to convert organic matter to organic carbon based on assumption that organic matters contain 58% of organic carbon (Schumacher, 2002). Analysis of variance (ANOVA) test at $P \leq 0.05$ using SAS version 9.1 software was used to check the variance of pH and carbon content among the plots and Duncan's multiple range test (DMRT) were used to show and specify the difference among them (Table 1).

RESULTS

The soils of Awat-Awat Mangrove Forest were acidic with an average pH of 4.63. Furthermore, the lowest pH in this mangrove forest was 3.93 in Plot 6 (soil under dominance of *Rhizophora mucronata*) whereas the highest was 5.41 in Plot 8 (soil under dominance of*S. alba*). From ANOVA at $P \leq 0.05$, pH was found significantly different between plots. Soil carbon content of Awat-Awat Mangrove Forest was different among the plots. The average of soil carbon content in mangrove forest was 3.29%. The highest carbon content was found in Plot 6 (soil under dominance of *R. mucronata*) whereas the lowest carbon content was found in Plot 8 (soil under dominance of *S. alba*). According to ANOVA test at $P \leq 0.05$, soil carbon content in 9 plot of this mangrove forest was significantly different and from Duncan's multiple range test (DMRT) it was clearly seen there were significant difference among them (Table 2).

Table 1. Dominant species of each plot in Awat-Awat mangrove forest, Lawas, Sarawak, Malaysia.

Plot	Dominant species	Local name
1	*Rhizophora apiculata*	Bakau minyak
2	*Lumnitzera racemosa*	Nggeriting putih
3	*Nypa fruticans*	Nipah/Apung
4	*L. littorea*	Nggeriting merah
5	*Xylocarpus granatum*	Nyireh bunga
6	*R. mucronata*	Bakau kurap
7	*Bruguiera parviflora*	Lenggadai
8	*Sonneratia alba*	Perepat
9	*S. caseolaris*	Pedada

Table 2. Mean of soil carbon content and pH of Awat-Awat mangrove forest at Lawas, Sarawak.

Plot	Species dominance	pH	C Content (%)
1	*Rhizophora apiculata*	4.20^{cde}	2.72^{cde}
2	*Lumnitzera racemosa*	4.65^{c}	3.62^{bcd}
3	*Nypa fruticans*	4.61^{c}	4.08^{bc}
4	*L. littorea*	4.68^{c}	2.22^{de}
5	*Xylocarpus granatum*	4.19^{cd}	2.30^{de}
6	*R. mucronata*	3.93^{d}	6.24^{a}
7	*Bruguiera parviflora*	4.76^{bc}	4.60^{b}
8	*Sonneratia alba*	5.41^{a}	1.73^{e}
9	*S. caseolaris*	5.24^{ab}	2.08^{de}

*Mean with same letter for each variable are not significantly different at $P \leq 0.05$ using ANOVA, Duncan's multiple range test was used to check the differences among the station.

DISCUSSION

Soil pH of in every plot of this mangrove forest were acidic with range of 3.93 to 5.41. The most acidic one was found in Plot 6 soil under *R. mucronata* dominance. Average pH value in this mangrove forest were lower compared to other research areas that were done by other researchers but still in the comparable values (Table 3). Generally, soils of mangrove are neutral to slightly acidic due the sulphur-reducing bacteria and the presence of acidic clays, but in Malaysia there are mangroves with very acidic brackish waters due to the aeration of soil sulphates, forming sulphuric acid (Peter and Sivasothi, 2001).

According to Duncan's multiple range test (DMRT), there were 4 groups of soil pH among 9 plots which were significantly different among each other. They were Plots 8 and 9; Plots 7 and 9; Plots 1, 2, 3, 4, 5 and 7; Plots 1, 5 and 6. Soil pH in plots with same group was not significantly different among each other (Table 2).

Soil carbon content of this mangrove forest varied. It ranged from 1.73 to 6.24% with average mean of 3.29%. The highest soil carbon content in this mangrove forest was 6.24% and the area was dominated by *R. mucronata* (Plot 6) whereas the lowest soil carbon content was 1.73% under dominance of *S. alba*. According to DMRT test, there were 5 groups of soil carbon content which were significantly different whereas soil carbon content with same group was not significantly different (Table 2).

Soil carbon studies of mangrove have been carried out in many places with many different site characteristics. In the present study, carbon content of soil under dominance of *R. apiculata* in Awat-Awat Mangrove Forest was comparatively similar to carbon content in soil under *R. mangle* in Sepetiba Bay, Brazil (Lacerda et al., 1995). Furthermore, the soil carbon content of Awat-Awat mangrove forest was comparable with the values recorded in elsewhere (Table 4). Studies revealed that the soil carbon content is different and varies from one different place to another. Different species dominance gave different results to the content of soil carbon.

Moreover, Lacerda et al. (1995) also noted an accumulation of strong evidence for significant differences among mangrove soils due to the presence of different mangrove species.

Conclusion

Soils of this mangrove forest were acidic and the acidity

Table 3. Soil pH of several mangrove forest.

Author	Site characteristics	Average pH value
Sukardjo (1994)	Mangrove forest of the Apar Nature Reserve, East Kalimantan, Indonesia. With species of *Avicennia* and *Ceriops*.	4.35 to 5.29 (Avicennia), 3.70 to 4.20(Ceriops)
Wakushima et al. (1994a)	Mangrove forest of Amphur Laemngop, Thailand. With species of *R. apiculata R. mucronata. C. tagal, Excoecaria agallocha,* and *Lumnitzera racemosa*.	4.27±0.05 to 7.32±0.09
Wakushima et al. (1994b)	Mangrove forest of southern Japan. With species of *R. stylosa.*	3.31 to 8.16
Ukpong (1995)	Mangrove swamp of southeastern Nigeria. With species of *Rhizhophora spp* and *Nypa fruticans.*	2.9 to 3.8
Mahmood et al. (2005)	Mangrove forest of Kuala Selangor, Malaysia. With species of *Bruguiera parviflora*	6.77±0.05 to 7.07±0.04
Muhibbullah et al. (2005)	Sundarband mangrove forest, Bangladesh. With various species.	6.3 to 7.13
Shazra et al. (2008)	Mangrove forest of HA. Baarah, Maldives. With species *R. mucronata* and *Hibiscus tiliacius*	6.0 (*R. mucronata*), 6.5 (*H. tiliacius)*
Rambok et al. (2010)	Wildlife sanctuary mangrove forest, Sibuti, Malaysia. With species of *R. apiculata*.	3.34
Present study	Awat-Awat Mangrove Forest, Lawas, Sarawak, Malaysia. With species of *R. apiculata*	3.93 to 5.41

Table 4. Soil total carbon of several mangrove area.

Author	Site characteristics	Carbon content (%)
Sukardjo (1994)	Mangrove forest of the Apar Nature Reserve, East Kalimantan, Indonesia	3.96% (*Avicennia* forest) 11.40% (*Ceriops* forest)
Lacerda et al. (1995)	Itacuruca Experimental Forest, Sepetiba Bay, Brazil	2.70 to 2.80% (under *Rhizophora mangle)* and 3.80 to 6.10% (under *Avicennia schaueriana)*
Chmura et al. (2003)	World mangrove and salt marshes (western and eastern Atlantic and Pacific coasts)	11.1%
Shazra et al. (2008)	Mangrove forest of Maldives	0.196 and 0.017%
Rambok et al. (2010)	Sibuti, Malaysia (Wildlife sanctuary mangrove forest)	12.18%
Ray et al. (2011)	Sundarbands, India (natural mangrove forest)	0.51 to 0.65%
Chandra et. al. (present study)	Awat-Awat mangrove forest, Malaysia	1.73 to 6.24%

varied according to plant species dominance. The soil under dominance of *R. mucronata* was most acidic (pH 3.93). Soil carbon content of this mangrove forest varied according plant species dominance. The highest soil carbon content was 6.24% and the area was dominated by *R. mucronata* whereas the lowest soil carbon content was 1.73% under dominance of *S. alba*. Soil carbon storage and pH at this mangrove forest varied according to plant dominance.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Teaching the effect of variables on the brightness of a light bulb in a simple electrical circuit using a pneumatic system model (PSM)

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An experiment-based analogical pneumatic system model (PSM) was developed in this study for the purpose of teaching 5th grade students (11 years old) the variables that have an effect on the brightness of a light bulb in a simple electric circuit. Understanding the analogical relationship between source and target in teaching the variables that have an effect on the brightness of a light bulb in a simple electric circuit using a PSM. Understanding the analogical relationship between the effect on the brightness of a light bulb when the number of light bulbs is kept fixed but the number of batteries is increased and the effect on the size of an inflated balloon and the distance traveled by the rocket balloon when the number of balloons is kept fixed but the cycle of the air pump is increased. Understanding the analogical relationship between the effect on the brightness of a light bulb when the number of batteries is kept fixed but the number of light bulbs is increased and the effect on the size of the inflated balloon and the distance traveled by the rocket balloon when the cycle of the air pump is fixed but the number of balloons is increased.

Key words: Brightness of a light bulb, a simple electrical circuit, pneumatic system model (PSM).

INTRODUCTION

The importance of electricity and its use in daily life are reasons that the topic of electricity is included in curriculum for students at early ages. It is not easy however to teach students the basic concepts of electricity and equally difficult for them to grasp and understand these concepts. Various studies can be found in the literature about learning difficulties (Chambers and Andre, 1997; Engelhardt and Beichner, 2004; McDermott and Shaffer 1992; Shipstone et al., 1988) and misconceptions among students in this context (Cohen et al., 1983; Dupin and Johsua, 1987; Heller and Finley, 1992; Lee and Law, 2001; Millar and King, 1993; Osborne, 1981, 1983; Psillos and Koumaras, 1988). Also since explaining electrical phenomena has to do with

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Table 1. Pneumatic System Model source-target concept relationship.

Pneumatic system model	
Source concepts	**Target concepts**
The air released by the air pump	Potential of battery
Air pump: The component of the model that converts electrical energy into kinetic energy and the source of the air.	Battery: The component of the circuit that converts chemical energy into electrical energy and the source of the potential.
Transparent plastic hose: The air released from the air pump moves in the system through the transparent plastic hose.	Power line: The chemical energy in the battery is transmitted to the circuit components in the form of electrical energy with the help of the power line.
Valve: When the valve is open, the air moves in the system, the system is complete and the balloon inflates.	Switch: When it is closed, an electric current is created with the help of the electrical charges, the circuit is complete and the light turns on.
Plastic balloon	Light bulb
Size of the inflated plastic balloon	Brightness of the light bulb
Movement of the rocket balloon (As the size of the inflated plastic balloon increases, the distance the rocket balloon travels increases) Conversion of energy The electrical energy in the air pump converts into kinetic energy. Kinetic energy turns into potential energy when the plastic balloon inflates. The potential energy turns into kinetic energy with the movement of the rocket balloon.	Conversion of energy The chemical energy in the battery turns into electrical energy. The electrical energy in the light bulb turns into heat and light energy.

abstract physical concepts and microscopic interactions, it is important that activities to increase students' understanding are designed so that a relationship can be formed with concrete concepts (Yiğit and Özmen, 2006). Models are frequently used in this context to teach concepts to students. Models are temporary schemes or structures that correspond to real objects, events, or classes of events. Models have explanatory power. Students can present their results to students, teachers, and others with models. The science and technology standards connect students to the designed world, present them experimentation in making models of objects and systems, and introduce them to laws of nature through their understanding of how technological objects and systems work (National Research Council (NRC), 1996). An experiment-based analogical pneumatic system model (PSM) was developed in this study for the purpose of teaching 5th grade students (11 years old) the variables that have an effect on the brightness of a light bulb in a simple electric circuit.

PSM source-target concept relationship

The air released by the air pump (battery) that creates the air flow in the system reaches the plastic balloon (light bulb) with a transparent plastic hose (power line) and the balloon inflates (light turns on). The size of the inflated balloon (brightness of the light bulb) varies according to the number of the balloons (number of the light bulbs) and the cycle (number of batteries) at which the air pump is operated (Table 1). Putting the balloons in the PSM inside the plastic bags is important in terms of making the two balloons inflate equally and demonstrating that there is a limit to how bright the light bulb can get. This is because the brightness of the light does not increase the more the number of batteries since it would burst if it did. Similarly, the balloon inflated inside the plastic bag would burst at some point.

Conversion of energy

The experiment-based activity that used a PSM was carried out in three stages:

(1) Stage 1: Understanding the analogical relationship between source and target in teaching the variables that have an effect on the brightness of a light bulb in a simple electric circuit using a PSM.
(2) Stage 2: Understanding the analogical relationship between the effect on the brightness of a light bulb when the number of light bulbs is kept fixed but the number of batteries is increased and the effect on the size of an inflated balloon and the distance traveled by the rocket balloon when the number of balloons is kept fixed but the cycle of the air pump is increased.
(3) Stage 3: Understanding the analogical relationship

Figure 1. Energy conversion in a simple electrical circuit.

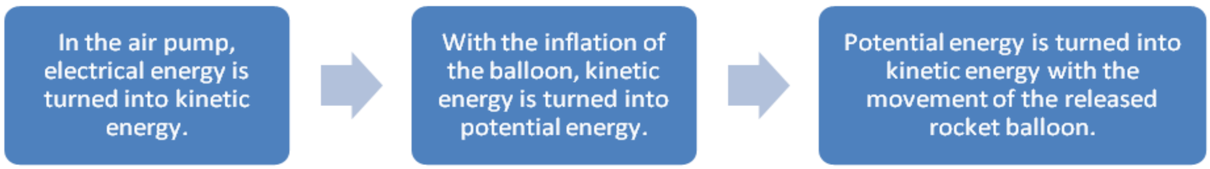

Figure 2. Energy conversion in analogical models (PSM 1, 2, 3).

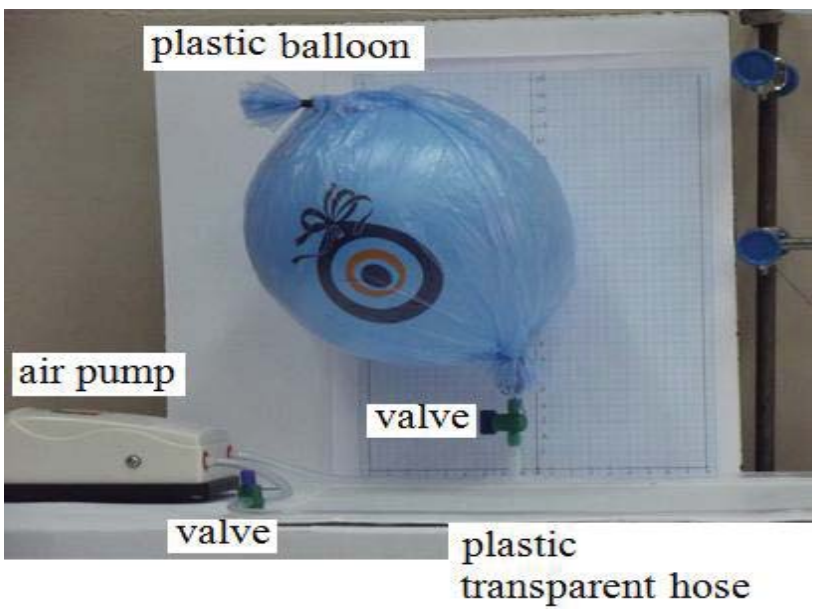

Figure 3. Pneumatic system model (PSM).

between the effect on the brightness of a light bulb when the number of batteries is kept fixed but the number of light bulbs is increased and the effect on the size of the inflated balloon and the distance traveled by the rocket balloon when the cycle of the air pump is fixed but the number of balloons is increased (Figures 1 and 2).

First stage: The analogical relationship between the PSM and the simple electrical circuit

The figures demonstrating the experiment set-up for the PSM that forms the basis of the experiment (Figure 3) and the simple electrical circuit (Figure 4) show which circuit component corresponds to which component in the model. To better understand the experiment-based model in the next stages, this relationship must be kept in mind.

Second stage: Using the PSM to teach the effect on the brightness of a light bulb when the number of light bulbs is kept fixed while the number of batteries is increased

In this stage of the experiment-based PSM activity, a study will be made of the effects of keeping the number of light bulbs in the simple electrical circuit fixed while the number of batteries is increased. The tools and

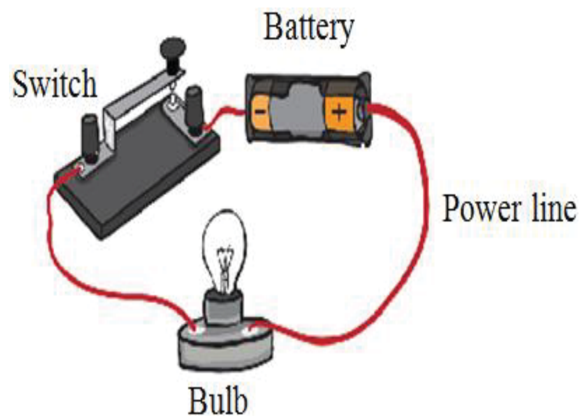

Figure 4. Simple electrical circuit.

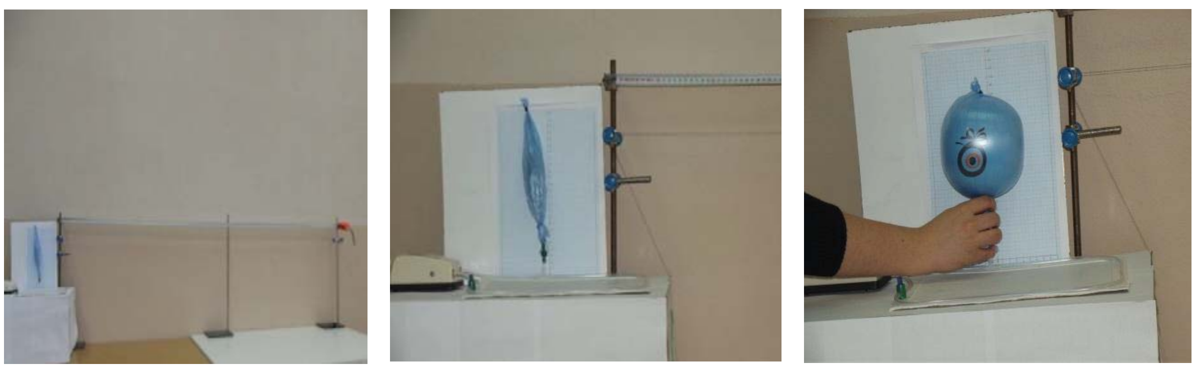

Figure 5. PSM 1.

Figure 6. PSM 2.

equipment needed for this stage are: an air pump, a plastic transparent hose, 2 valves, 1 plastic balloon, 1 plastic bag, 1 straw, rope, steel tape measure, 2 supports, 4 connection pieces, graph paper and a white metal plate.

PSM 1 and 2 shown in Figures 5 and 6 should be set up horizontally and the air pump that will be delivering air to the system should be connected to the transparent plastic hoses. Then valve 1 should be connected to the transparent plastic hoses as in Figure 3. The air pump in the PSM delivers air into the system and the amount of air entering the system varies according to the cycle at which the air pump is operating. The air pump in PSM 1 should be operated at Cycle 1 (2, 5 L/min), the one in PSM 2 should be operated at Cycle 2 (5 L/min).

The transparent plastic hose should fill up with air when

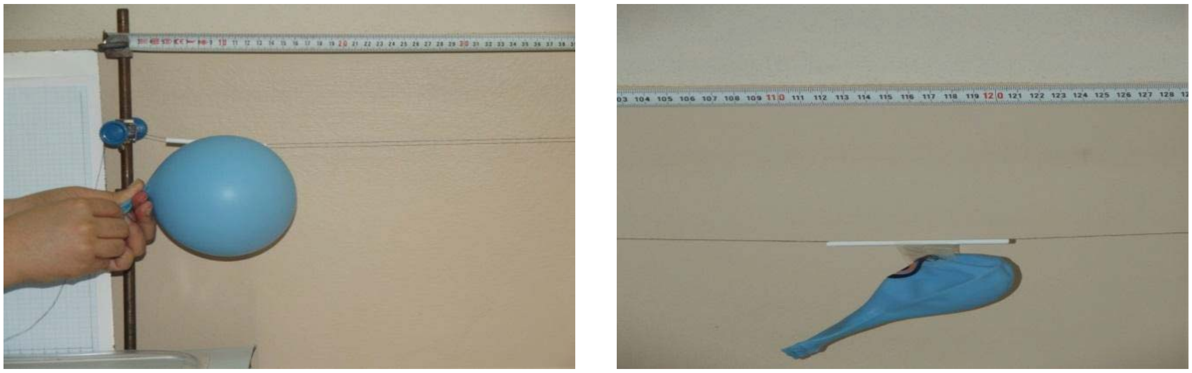

Figure 7. PSM 1.

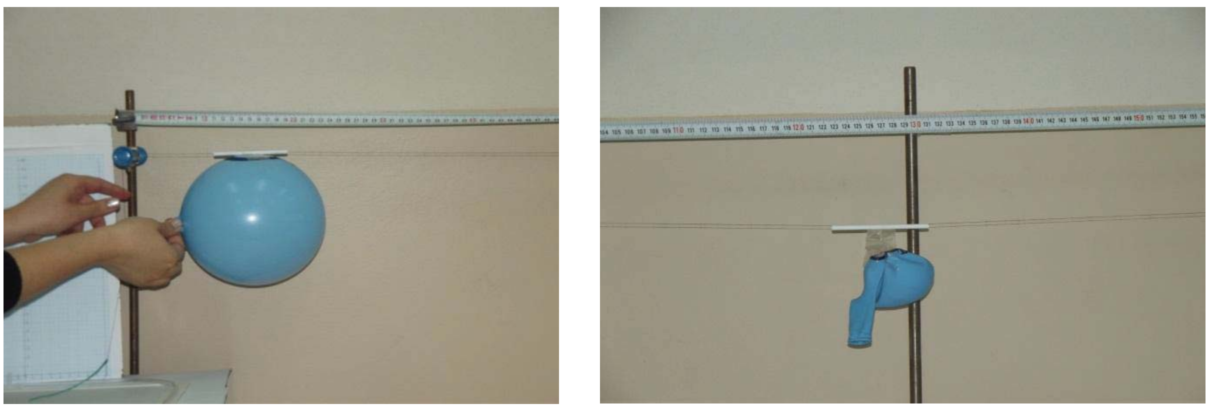

Figure 8. PSM 2.

the air enters the system and the plastic balloon should start inflating. The valve should be left open so that the balloon can inflate. The air pump should be operated for 1 min. After 1 min, the pump should be stopped so that the air in the system is kept fixed. The size of the inflated balloon should be observed and it should be measured with a piece of graph paper fixed to the back of the balloon. Figures 5 and 6 should be examined to compare the sizes of the balloons in the analogical models.

The system up until this point is closed as in a simple electrical circuit. However, in order to form an analogical relationship with the conversion of energy in the simple electrical circuit, a straw with a piece of string passed through it should be attached to the balloon so that the rocket balloon is separated from the system. The rocket balloon in the analogical model uses the air inside it as fuel and from the moment it is left free, it jets forward until the air is completely pushed out, stopping when the air is depleted. The distance traveled by the rocket balloon in the analogical model should be measured and the distances the rocket balloons traveled should be compared for PSM 1 and 2. Since there will be a release of air with the release of the plastic at the tip of the rocket balloon, PSM 1 and 2 are now open systems.

In this part of the experiment, the rocket balloon in PSM 1 operated at Cycle 1 of the air pump in the first situation (Figure 7) changed its place by 120.5 cm. In the second situation (Figure 8), the air pump was operated at Cycle 2 and the rocket balloon in PSM 2 changed its place by 130.5 cm. PSM 2 is represented two batteries in series charging one bulb in circuit.

Third stage: Using the PSM to teach the effect on the brightness of a light bulb when the number of batteries is kept fixed and the number of light bulbs is increased

In this stage of the experiment-based PSM activity, a study will be made of the effects of keeping the number of batteries in the simple electrical circuit fixed while increasing the number of light bulbs. The tools and equipment needed for this stage are: an air pump, a transparent plastic hose, 3 valves, 2 plastic balloons, 2 plastic bags, 1 straw, string, steel tape measure, 2 supports, 4 connection pieces, graph paper and a white metal plate.

Figure 9. PSM 3.

Figure 10. PSM 3.

PSM 3 shown in Figure 9 is set up horizontally and the air pump that will be delivering air to the system should be connected to the transparent plastic hoses. Then the valve is connected to the transparent plastic hoses as in Figure 9. The air pump in PSM 3 delivers air and the amount of air entering the system varies according to the cycle at which the air pump is operated. The air pump in PSM 3 should be operated at Cycle 2 (series connection of 2 batteries). PSM 3 is represented with two batteries in series charging two bulbs in series.

The transparent plastic hose should fill up with air when the air enters the system and the plastic balloon should start inflating. The valve should be left open so that the balloon can inflate. The air pump should be operated for 1 min. After 1 min, the pump should be stopped so that the air in the system is kept fixed. The size of the inflated balloon should be observed. It should be measured with a piece of graph paper fixed to the back of the balloon. The sizes of the balloons in PSM 2 and 3 should be compared.

The system up until this point is closed as in a simple electrical circuit. However, in order to form an analogical relationship with the conversion of energy in the simple electrical circuit, a straw with a piece of string passing through it should be attached to the balloon so that the rocket balloon is separated from the system. The distance the rocket balloon travels should be measured. The distance the rocket balloon travels in the analogical model Figure 5 should be recorded. The distances traveled by the rocket balloons in PSM 2 and 3 should be compared. Since there will be a release of air with the release of the plastic at the tip of the rocket balloon, in this situation PSM 3 is now an open system.

In this part of the experiment (Figure 10), the air pump was operated at Cycle 2 and the rocket balloon changed its place by 47 cm. When the number of balloon (light bulb) is kept fixed but the cycle of air pump (the number of battery) is increased, size of the inflated plastic balloon (the brightness of a light bulb) is increased. When the cycle of air pump (the number of battery) is kept fixed but the numbers of balloons (the number of light bulb) are increased, sizes of the inflated plastic balloons (the brightness of a light bulb) are decreased.

In series circuits, the total potential of between the ends of each resistor is equal to potential of between the ends of generator. When the number of bulb in series is kept fixed, the number of battery in series is increased, potential is increased. Potential that drop each bulb in series is increased at the same rate. Current that flow through each bulb in series is increased. As a result, the brightness of a light bulb in series is increased. When the number of battery in series is kept fixed, the number of bulb in series is increased, potential is shared. Potential that drop each bulb in series is decreased at the same rate. Current that flow through each bulb in series is decreased. As a result, the brightness of a light bulb in series is decreased. When the number of bulb in series is kept fixed, the number of battery in series is increased, electrical energy is increased. Electrical energy that drops each bulb in series is increased at the same rate. As a result, the brightness of a light bulb in series is increased. When the number of battery in series is kept fixed, the number of bulb in series is increased; electrical energy is shared between the bulbs. Electrical energy that drops each bulb in series is decreased at the same rate. As a result, the brightness of a light bulb in series is decreased.

PSM differences between source-target concepts

In the analogical model there are similarities and differences between the source and target concepts. To avoid misconceptions, the differences must be set forth (Duit, 1991; Kesercioğlu et al., 2004). The differences between the source and target concepts in the PSM are therefore stated below: While in a simple electrical circuit, the electric current returns to the battery, in the PSM, the air does not return to the pump. Although a simple electrical circuit is a closed system, the PSM is an open system in order to demonstrate how energy is converted. In a simple electrical circuit the battery is not separated from the circuit for the light to be turned on. In the PSM, however, the air pump is stopped to maintain the system. In a simple electrical circuit, the switch has to be closed for the light to turn on whereas in the PSM, the valve has to be open for the balloon to inflate. Transmission of air from air pump to balloon is one-way. Also, no air flows through the balloons, but charge flows through the bulb in the circuit.

Conclusion

The experiment-based PSM demonstrates to students the dependent, independent and controllable variables that affect the brightness of a lamp connected to a simple electrical circuit, thus helping them to develop their scientific process skills in estimating, observing, collecting data, performing experiments, problem-solving and creating models. This model, which is used in teaching applications, has produced successful results in teaching the variables that affect the brightness of a lamp in a simple electrical circuit. The model developed in this study may be used as an alternative activity before or during the teaching of simple electrical circuits. Furthermore, it is believed that the model is a good example that can be used to improve techniques and student skills in the area of guided inquiry, the basis of many academic programs in many countries. This analogical model has been developed to be applied to 5th grade students (11 years old) for teaching the variables that have an effect on the brightness of a light bulb in a simple electric circuit and the effectiveness of this model on success, attitude, mental modelling and misconceptions.

Conflict of Interest

The authors have not declared any conflict of interest.

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