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PROJECT-BASED LEARNING AND SOLAR ENERGY UTILIZATION USING LOCALLY DESIGNED SOLAR CONCENTRATOR: ENCOURAGING SUSTAINABLE DEVELOPMENT PRACTICES AMONG NIGERIAN SCIENCE STUDENTS

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Abstract

Emerging trends in education reforms have continued to call for quality education that willfoster the ability of learners to meet the challenges of the 21st century and encourage their participation in sustainable development issues. The wealth drawn from quality education form the basis to finding solutions to issues of national economy beginning from needs of rural people.The current economic recession in Nigeria radically challenges the system of education to shift from factory model of education to a more proactive system of education through PBL. Twenty secondary school students from Anambra State, Nigeria participated in the study. The study was an experiment that involved the participants in designing a solar concentrator using locally *available materials. The students used the designed solar concentrator to generate high temperatures at the focal region of the concentrator where the absorber was positioned. The incoming solar radiation was measured periodically for four days using pyranometer between 8.00 to 18.00 hours. The temperatures of the concentrator surface, the focal region (the absorber), the control, the ambient, the air within the aperture of the concentrator and outside the concentrator were monitored using mercury-in-glass thermometers. Results revealed that therise in temperature of the absorber was much higher than that of the control, concentrator surface and ambient temperatures. The behavior of the system was similar for all the days, with the maximum temperatures obtained at the absorber between 12.30 hours and 14.30 hours (*70ºC to 96 ºC*). The temperature of the collector varied between 43˚C and 45˚C while the ambient* temperature *varied slightly from about 30ºC to 32ºC. The results clearly showed that the designed solar concentrator was an effective solar cooker/solar furnace and could function better than most kerosene stoves which exude smoke and pollute the air. Collaborative workingin groups also enhanced the acquisition of soft and generic skills.*

Keywords
Project-Based Learning, Students, Sustainable Development, Solar Concentrator, Solar Energy

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1. Introduction

Science is a human intellectual construct which demands active participation, critical thinking, analytical thinking and problem solving skills by learners, if deeper learning is to take place. Over several years, research has continued to show that the factory model of education persistently used by most Nigerian teachers neither promotes students' active participation in the learning process nor encourage the acquisition of skills that could help learners face real-life challenges (Bamidele, & Oloyede, 2013;Opara & Waswa, 2013; Woldeamanuel, Atagana & Engida,2013 & Taurina, 2007). In a world that is becoming increasingly more complex and more competitive; where education reforms advocate for interdisciplinary approaches, the critical need to shift from a model which Kesley (2013) described as lifeless, frustrating, unexciting, boring and bureaucratic in nature is underscored. In the view of Watters (2015) factory model do not engender deeper learning. Deeperlearning fosters in learners the 21st century skills they should master in order to develop a keen understanding of academic content and apply their knowledge to problems in the classroom and on the job.(Vander Ark & Schneider, 2014)

Hence, several advocates of progressive education and constructivists approach, assert that PBL is an instructional model which promotes deeper learning, higher-levelthinking and intra-personal skills (Larmer, Mergendoller & Boss, 2015; Pellegrino & Hilton 2012). The fundamental underpinning of PBL is classroom activity that emphasizes student- centered projects and shifts away from teacher-centered instruction. Students' active engagement in conducting and designing projects exposes them to investigative processesand collaborative working in groups on tasks geared towards solving real-life problems. In the process of carrying out projects, students also learn how to plan, gather information, synthesize and analyze information gathered, manage time, record results and throughcritical thinking and deductive reasoning draw appropriate conclusions related to data (Tamim & Grant, 2013; Hernandez-Ramos and De La Paz, 2009).

Despite several studies in favour of PBL, its implementation in Nigerian secondary schools is still scrubby. Major reasons attributed to non-implementation of PBL are that teachers do not possess the prerequisite knowledge to foster active-based learning and therefore do not have the capacity to adopt new instructional strategies, management and design of PBL (Salman, Olawoye & Yahaya, 2011; Mitchell, Foulger, Wetzel & Rathkey, 2009). Yet, more than ever before, the challenges facing Nigerians today call for more proactive system of education that could foster in the learners, generic and soft skills (communication, team-work, leadership, interpersonal relationship, critical thinking, and creativity) and engage them in thought-provoking real life problems.

The main source of energy for cooking and heating in rural areas of Nigeria where 70% of the population live is still firewood and charcoal. Kerosene has even become very expensive, scarce and unaffordable for the average rural dweller. The principle of sustainabledevelopment is fundamentally concerned with the maximization of well-being of human beings today while also bearing in mind the welfare of future generations [Organization for Economic Cooperation and Development (OECD, 2001)]. Studies have shown that frequent exposure to smoke and indoor air pollution resulting from cooking with firewood and charcoal not only leads to loss of vision among ageing women but also a significant cause of death and disability in chronic obstructive pulmonary disease of women(WHO, 2009). Thus, to reduce carbon dioxide emissions, global initiatives on environmental sustainability have continued to stress the reduction of dependency on fossil fuels and the improvement in energy efficiency using alternative sources of energy (Abbot, 2009). Accordingly, solar energy unlike wood, gas, oil and coal is the most environmentally clean, green, sustainable and renewable. It can also supply the global energy needs (Jacobson & Delucchi, 2009). Solar energy technology which is focused on making use of solar energy by converting it intoelectricity, heat and other forms of energy is therefore increasingly being advocated (Jacobson & Delucchi, 2011).

Hence, the advocacies for utilization of solar energy in Nigeria, where its use and application to improve the well-being of average Nigerians are yet to be realized.

2. Objectives of the Study

The objectives of this study are: (i) engaging secondary school students (who offer physics and chemistry at Senior Secondary Class (III) in constructing a solar concentrator (solar cooker) as a project in PBL (ii) to determine the workability and applicability of the solar concentrator on four different days (iii) to determine the variations in temperature of the absorberthat is positioned at the focus of the concentrator; temperature of the surface of the concentrator; ambient temperature and temperature of the control against hours of the day; to monitor the cone air temperature and immediate vicinity temperature (iii) to promote the acquisition of generic and soft skills among the students by rating students' level of demonstration of the skills during the project (iv) to encourage sustainable development practices among secondary school students.

The Senior Secondary Class III students engaged in this project had dealt with the topic on energy and renewal sources of energy in theory through the usual talk and chalk method.This project was further aimed at exposing students to be able to apply knowledge acquired in the classroom to solve real life problems currently facing a larger population of Nigerian nation with the price rise in kerosene and cooking gas.

3. Literature Review

Project based learning is an activity driven instructional model which was promulgated by John Dewey and later formalized by his student William Kilpatrick (Ulrich, 2016). The underpinning behind PBL that is opposed to the factory based model of education is centered on "learning by doing". PBL underscores deeper learning and the development of skills needed for success in the 21st century, if learners should meet the demands of a competitive market economy and survive the challenges of the contemporary society while being relevant in their various communities. PBL also has its root in constructivist theory of Piaget's prominence for knowledge construction by learners. Research has shown that knowledge is stored as a network of concepts in the brain of the learner and that learners construct knowledge by making connections between new information and their existing conceptual network or mental structures (Woolfolk & Margetts, 2013). The process of knowledge construction happens through the dialectical interplay of assimilation and accommodation. Assimilation is "an active process of making meaning out of experience (Eynon, Gambino & Török 2014; Heritage, Jones, Tobiason, and Chang, 2013) while accommodation is the changing of one's thinking in order to attain equilibrium (Piaget, 1977). Prior to accommodation, the individual's mind is in a state ofequilibrium (Atherton, 2011) but with the assimilation of new data, the mental structures becomeinadequate to tackle the new situation and must go through a process of change which may result in the alteration of organizational pattern. In other words, to gain equilibrium, learners must reorganize and change their initial concepts which often require challenging their current inadequate conceptions or views which they brought to the classroom. Equilibrium occurs when the learner is able to organize the new concepts with other concepts and has gained conceptual understanding manifested in the knack to view knowledge objectively and to address problems adequately. Thus, PBL challenges learners to construct real meaning of science concepts as they carry out projects related to real life situations as in the case of this study. The processes of accommodation, assimilation and equilibration which take place during the project work go a long way in fostering critical thinking, analytical and problem solving skills among learners.

PBL is further grounded on social constructivism. Social constructivism is based on the work of Piaget, Vygotsky, Bartlette, Bruner, Rogoff & Gestalt psychologists who theorized that learners' understanding is both individual and social processes (Woolfolk & Margetts, 2013). Social constructivism is entrenched in the theory which attributes social and cultural interactions as the means to which learners construct meaning. PBL exposes learners to a variety of activities which challenge their potentials to think creatively and actively participate in the learning process with a motivational interest. Learners' interest in the learning process is a fundamental consideration in PBL

Participation in a broad range of activities also allows learners to be able to appropriate the outcomes produced by democratically working in groups. Vygotsky believed that learning occurred in two stages: first, within the sociocultural environment and then individually as students process the learning experience and integrate the information into pre-existing mental structures or schemas. Therefore, learning cannot be separated from the social and cultural settings in which it took place.

Within the cultural and social setting of this study solar energy is plentiful, yet the excessive use of kerosene and other forms of fossil fuels which are expensive and have many implications on the climate delimits the appreciation of solar energy as a veritable source of energy (Ataide & Desai (2017). In addition, solar energy is free, environmentally friendly and non-pollutant. This study therefore, underscores its utilization in rural communities. The abilityof the students to construct the solar cooker in such a way that the collection of solar radiation was maximized (Yang, Liang & Chen, 2009); accentuates the significance of this project in fostering 21st century skills; as an approach which encourages interdisciplinary education and appreciates the ability of students in being resource persons who have capacity to address community problems. Hence, the transmission mode of learning, characterized by the factory model and teacher-centered system of education should be deemphasized in favour of PBL to enable learners appreciate the use of alternative energy sources in solving modern-day problems.

4. Materials and Method

In constructing a solar concentrator the device should be designed in such a way that it should promote the generation of higher temperatures. Solar energy technology entails the usage and application of solar energy in solving human problems such as production of heat energy for cooking, heating of homes, hot water for domestic use, cooling and refrigeration and solarpassive drying. In the concentrating type of solar collector, the incident solar radiation, after reflection at the surface of the concentrator are all brought to the focus of the concentrator, thus raising the temperature of the focal region far and above that of the ambient and the surroundings. The following materials were used for this project: aluminum sheet, ruler, sharp knife, mercury-in-glass thermometer, wood, iron rod, nuts and pyranomter.

The construction of the concentrator was carried out in stages. Each group of students (5 in a group) was provided with locally made aluminum sheets measuring 1.02m length by 1.0m width. In their various groups the students were required to construct a circle of diameter 1.0m on the aluminum sheet given to them. (Figure 1)

Earlier on, the students had designed and constructed prototypes of the concentrating solar collector using card board papers and discovered that a circle with diameter lying between 1.0m and 1.5m gives a good parabolic shape when folded if a sector of less than 25^{o}were cut out from it. Hence, in the next step they proceeded to mark out a sector of 20^{o} on the circle which was constructed on the aluminum sheet. They also marked out a small concentric circle of diameter 18 cm (Figure II). All the markings were carefully cut off. The shaded areas were cut off and discarded.

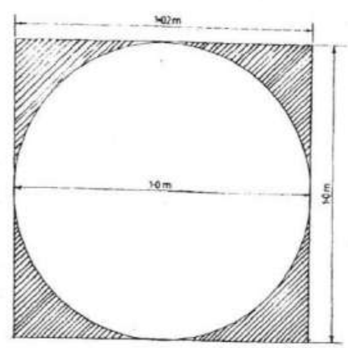

Figure 1: *A Square Aluminum Sheet with a 1m Diameter Circle inscribed in it*

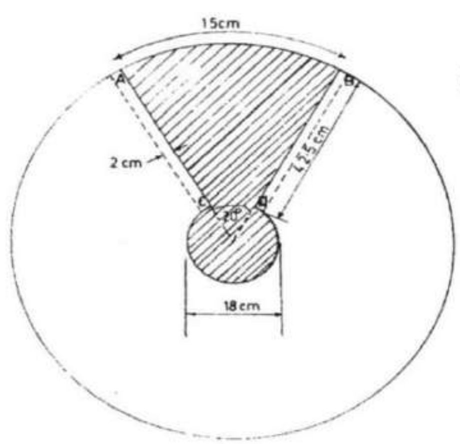

Figure 2: *The Circle with a 20^{0} Sector Marked Out*

Gradually, the resulting shape was folded until the edges AC slightly overlapped BD by 2.0cm. The two edges were joined together by riveting given rise to a parabolic shape i.e. the concentrating surface with a diameter of 90.0cm. The diameter of the hole at the base was 12.0cm (figure 3)

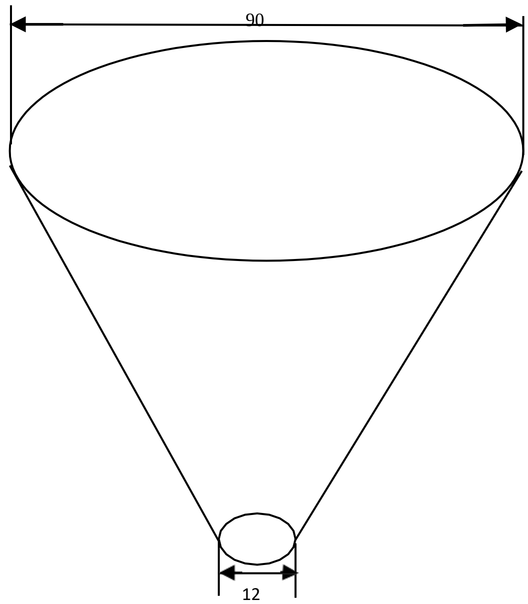

Figure 3: *Formed Concentrating Surface*

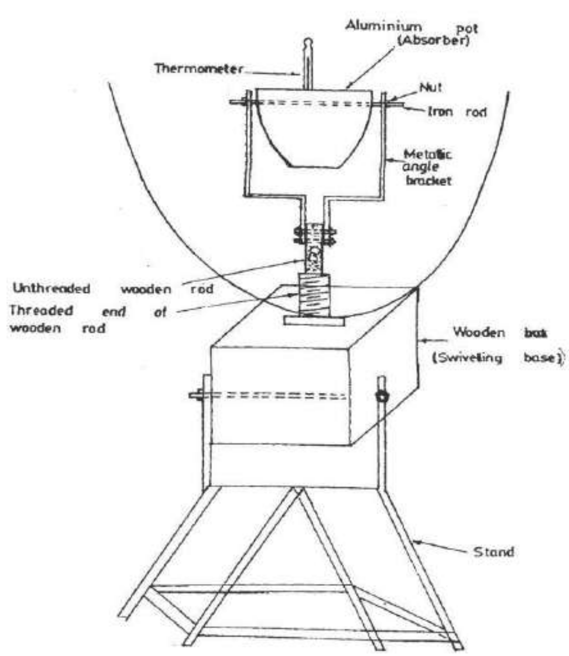

Figure 4: *The Assembled Solar Concentrator showing all the parts*

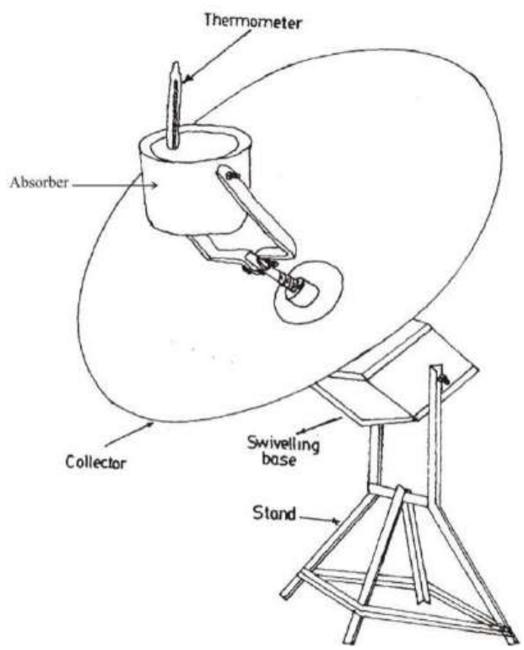

Figure 5: *Pictorial View of the Constructed Solar Concentrator (cooker) in Operation*

After construction, the students exposed the concentrator to beam radiation and monitored the temperatures of the absorber, the control, surface of concentrator, the ambient, air within the concentrator aperture and the air within the immediate vicinity of the concentrator (See Appendix). Figures 6, 7, 8 and 9 below show the fluctuations of solar radiation as functions of time.

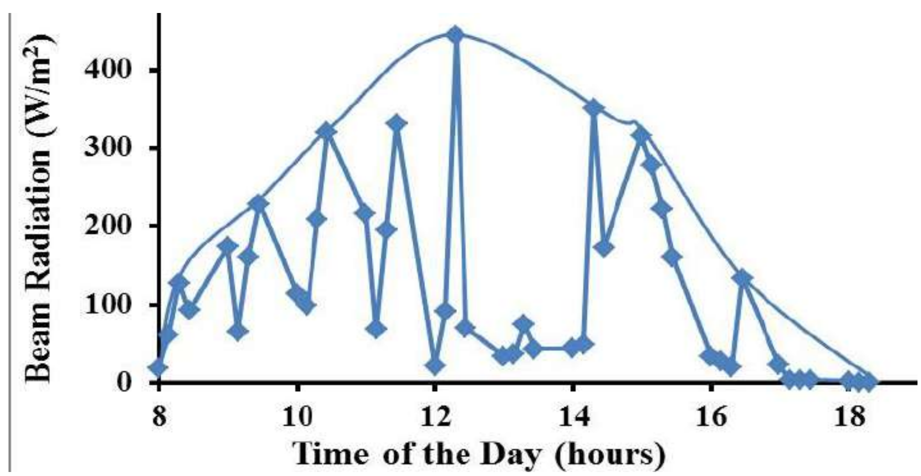

Figure 6: *Graph of Hourly Variation of Beam Radiation at Uli (Day, 1) Anambra State*

Figure 6 shows that beam radiation rises and falls due to the variations in weather conditions such as wind flow and cloudy atmosphere. There was intermittent shielding of the sun by cloud. A maximum value of beam radiation of about 460 W/m^2 was obtained at about 12.30 hours

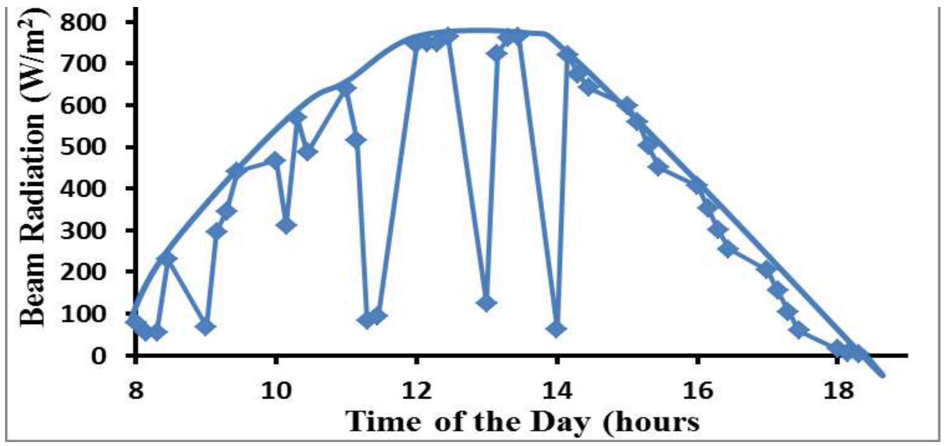

Figure 7: *Graph of Hourly Variation of Beam Radiation at Uli, (Day, 2) Anambra State*

Figure 7 also shows the fluctuations in the beam radiation due to the variations in climatic conditions. A beam radiation value of about 800 W/m^2 was obtained around the hours of 12.30 to 12.45. At about 13.50 hours, the value went down to 700 W/m^2 which gradually decreases to about 50 W/m^2 at about 18.00 hours.

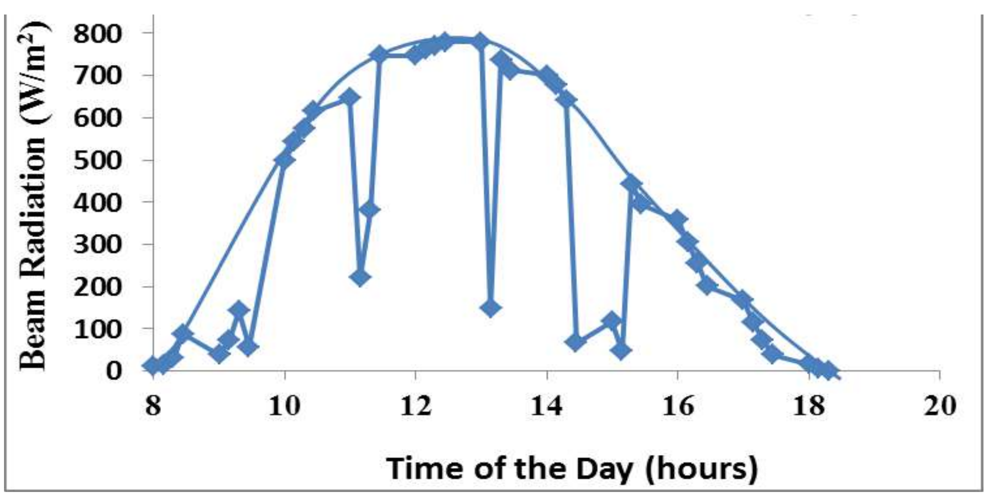

Figure 8: *Graph of Hourly Variation of Beam Radiation at Uli, (Day,), Anambra State*

Figure 8 shows the variation of beam radiation which follows the same trend as that of figures 6 and 7. The maximum value of beam radiation of about 780 W/m^2 at 13.00 hours was obtained. The values of 740 W/m^2 to 780 W/m^2 which fell on the solar concentrator within 11.45 hours and 13.00 hours made the solar concentrator effective for cooking.

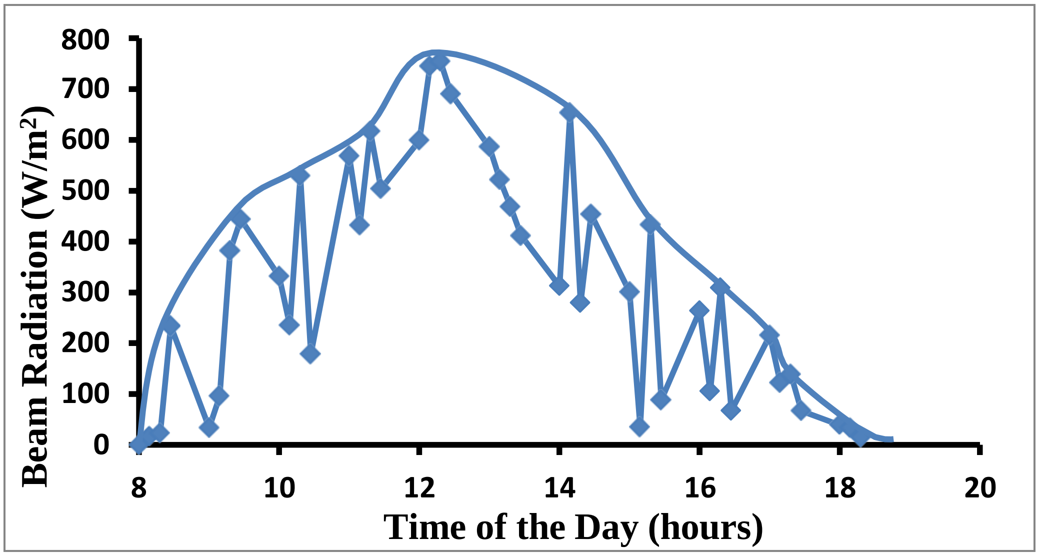

Figure 9: *Graph of Hourly Variation of Beam Radiation at Uli, (Day, 4), Anambra State*

Figure 9shows the variation in the beam radiation following similar trend with the maximum value of radiation of about 745 W/m^2 obtained at 12.15 hours. These values decrease gradually to 15 W/m^2 at 18.30 hours

These results of figures 1, 2, 3 and 4 confirm the nature of the variations in the beam radiation against the times of the day. The maximum beam radiations were obtained during the afternoon period of each day studied.

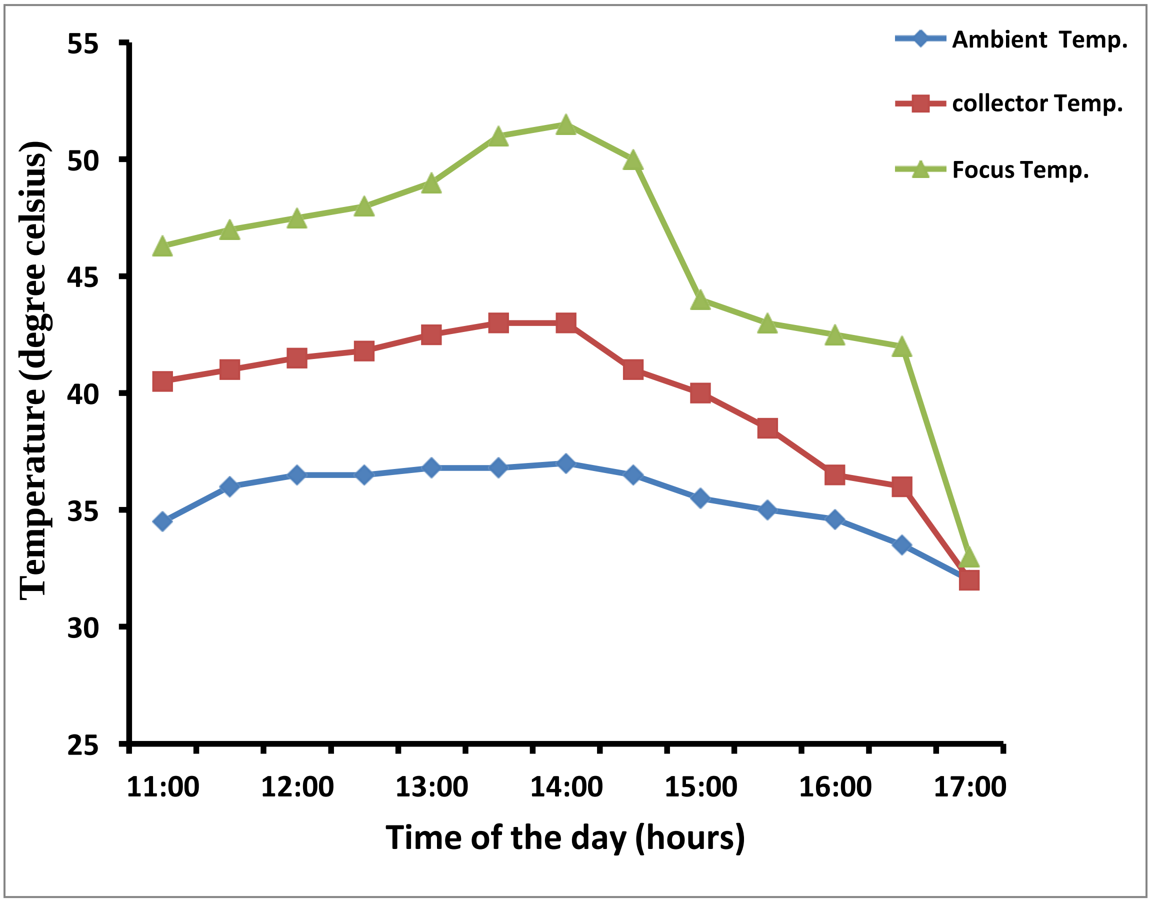

Figure 10: *Graph of Half Hourly Variation of the Temperatures at the Absorber, Concentrator and Ambient*

Figure 10 reveals the variation in the ambient temperature, the collector temperature and the temperature of the absorber against hours of the day. Variation of ambient temperature was within the range of 34 ºC to 32 ºC from 11.00 to 17.00 hours. The collector temperature slightly increases from 40ºC to 43 ºC at 14.00 hours and gradually decreases to 33 ºC at about 17.00 hours. The focus temperature increases from 46.30 ºC at 11.00 hours to a peak value of 51.50 ºCat 14.00 hours. This flows with a sharp decrease from 50 ºC at 14.30 hours to 44 ºC at 15.00 hours. The focus temperature was almost the same within 15.00 hours and 16.30 hours which dropped sharply to 33 ºC at 17 hours.

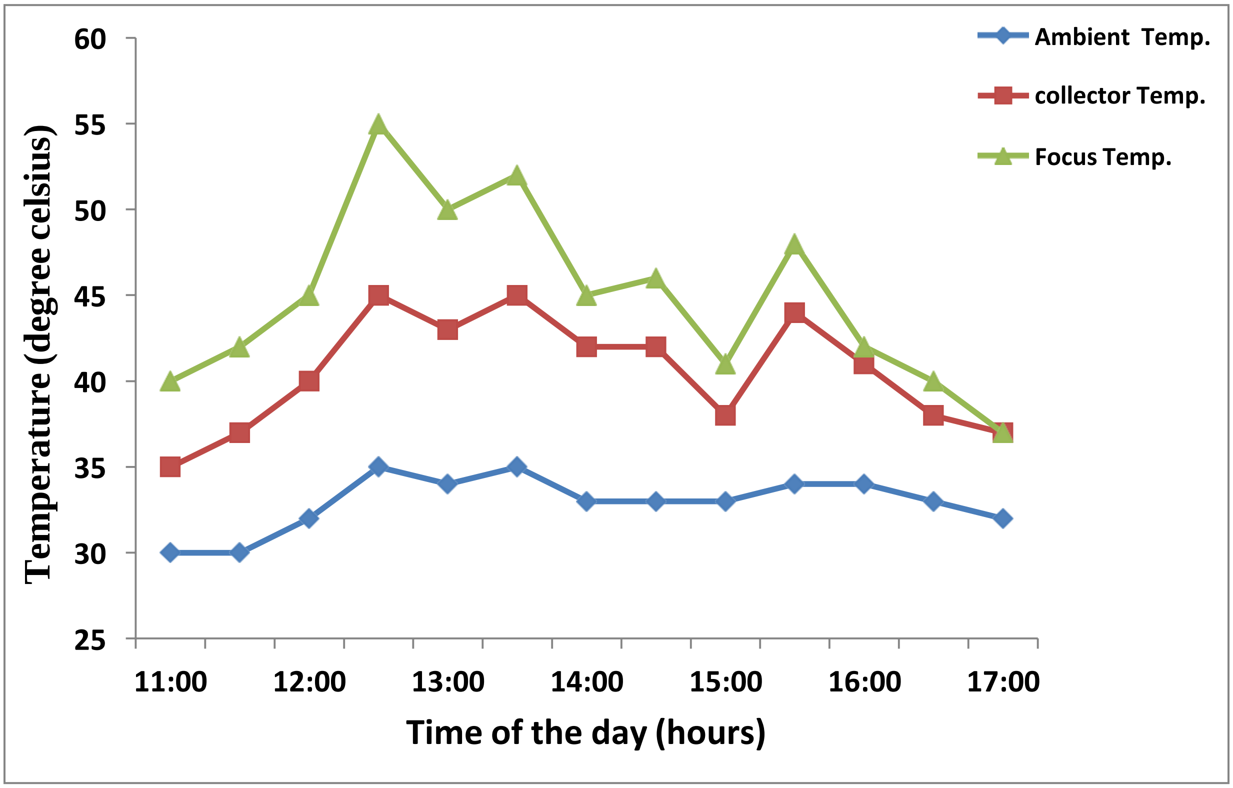

Figure 11: *Graph of Half Hourly Variation of the Temperatures at the Focus, Concentrator and Ambient (Day, 2)*

Figure 11 shows the variation in the ambient temperature, concentrator temperature and temperature at the focus which are similar in pattern when compared with figure 10. The ambient temperature varied the within the range of 30 ºC at 11.00 hours to 35 ºC at 12.30 hours. Collector temperature values ranged from 35 ºC at 11.00 hours to 44 ºC at 15.30 hours. Peak values of 45 ºC were obtained at 12.30 hours and 13.30 hours respectively. The collectortemperature decreased to 37 ºC at 17.00 hours.

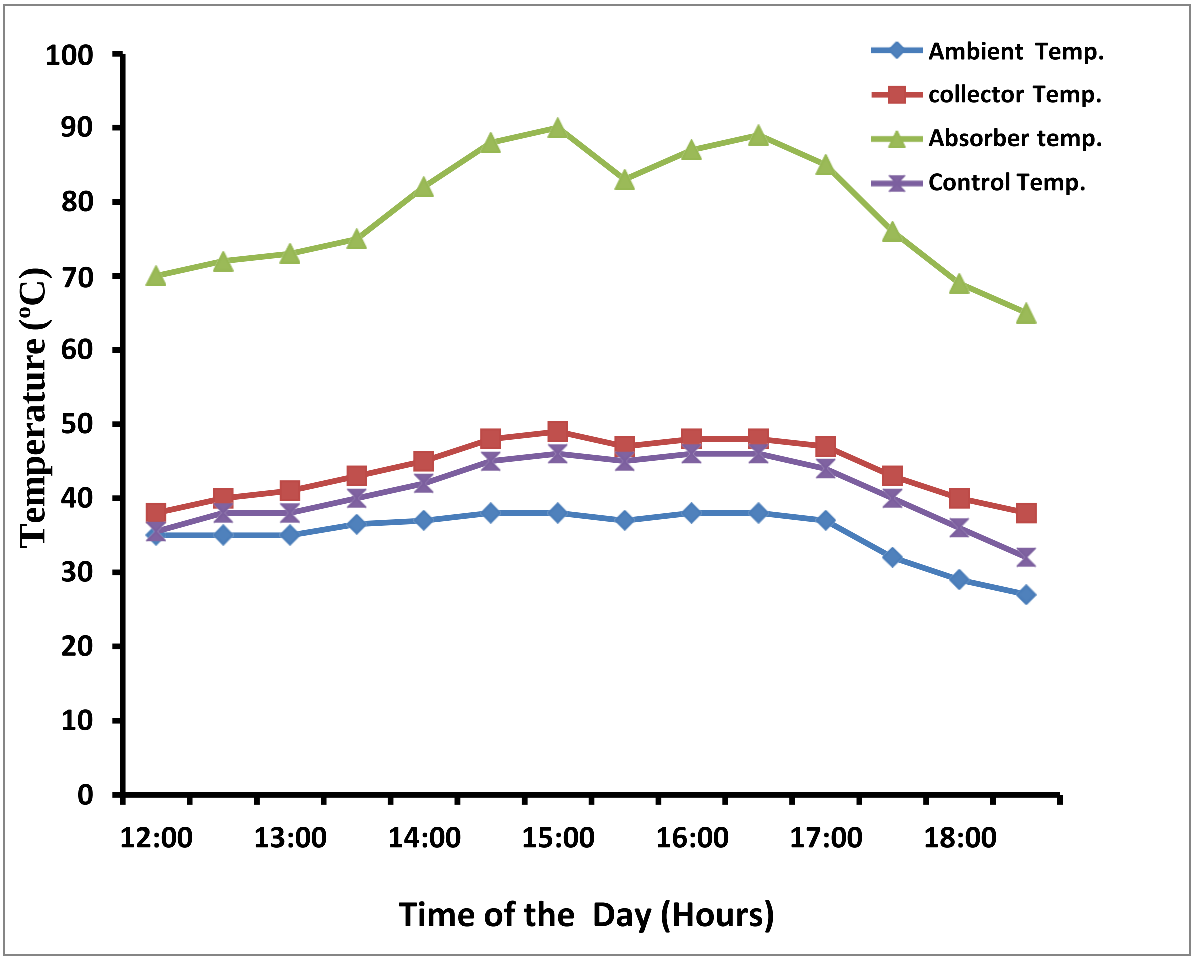

Figure 12: *Graph of Half Hourly Variations of the Temperatures of the Absorber, Control, Ambient and Collector*

Figure 12 shows the result which is similar to figure 11with the inclusion of the temperature variation of the control. At 12.00 hours the temperature of the control was 35.50 ºC while that of the absorber (Focus) was 70 ºC. The variation of temperature of the control was not too significant. Its variation ranged from 35.5 ºC at 12.00 hours to its peak at 46 ºC at 15.00 hours before decreasing to 32 ºC at 18.30 hours. Temperature of the absorber ranged from 70 ºC at 12.00 hours to its peaks at 90 ºC and 89 ºC at 15.00 hours and 16.30 hours respectively. It gradually decreased to 65 ºC at 18.30 hours.

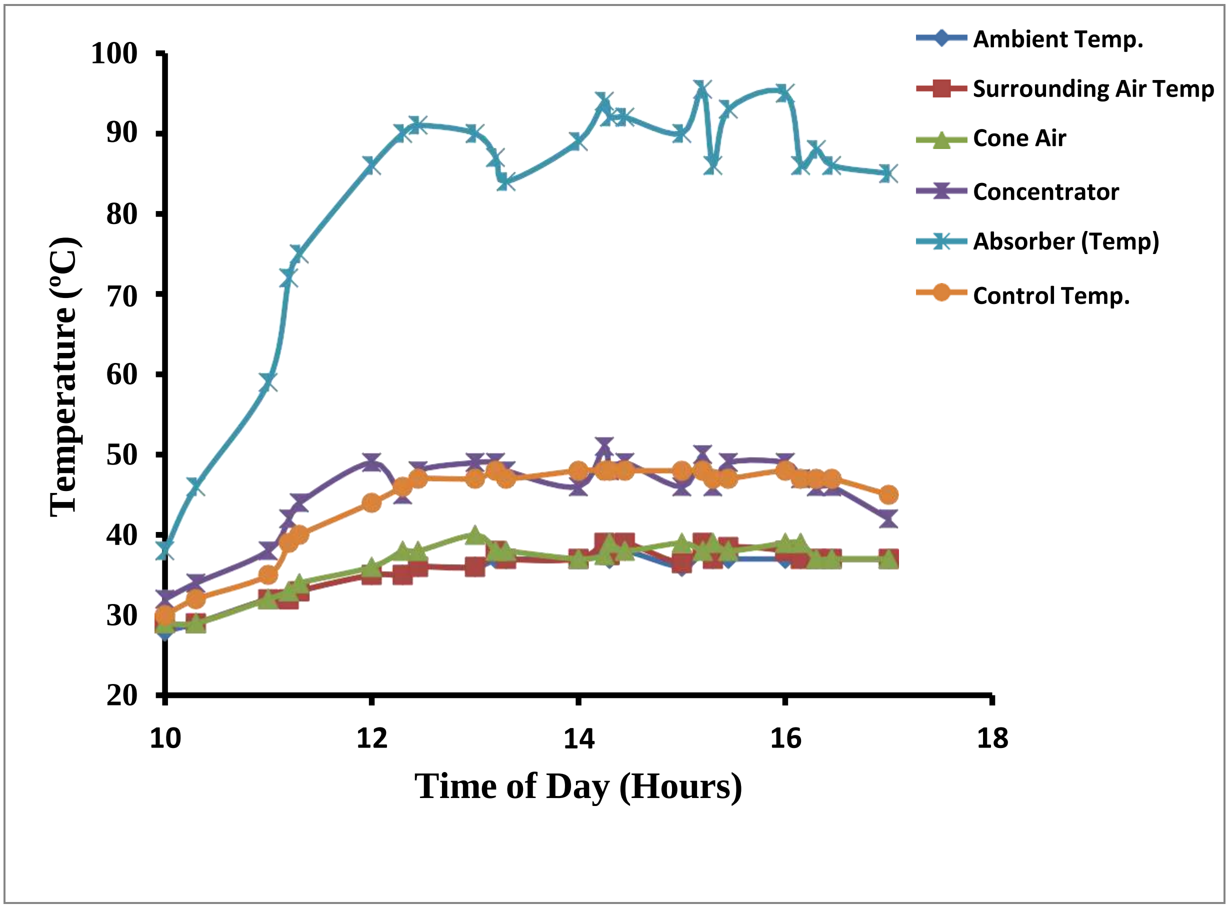

Figure 13: *Graph of Half Hourly Variations of the Temperatures of the Absorber, Control, Concentrator, Cone, Surrounding Air and Ambient Collector on day 3*

Figure 13 clearly shows that there is huge difference between the variations in the temperatures of the control and that of the absorber. While the control temperature variedbetween 28 ºC and 45 ºC , that of the absorber varied from 38 ºC, peaked at 90 ºC at 12.45 hours, 94 ºC at 14.25 hours; 95.5 ºC at 15.20 hours and 95 ºC by 16.00 hours before decreasing slightly to 85 ºC at 17.00 hours.

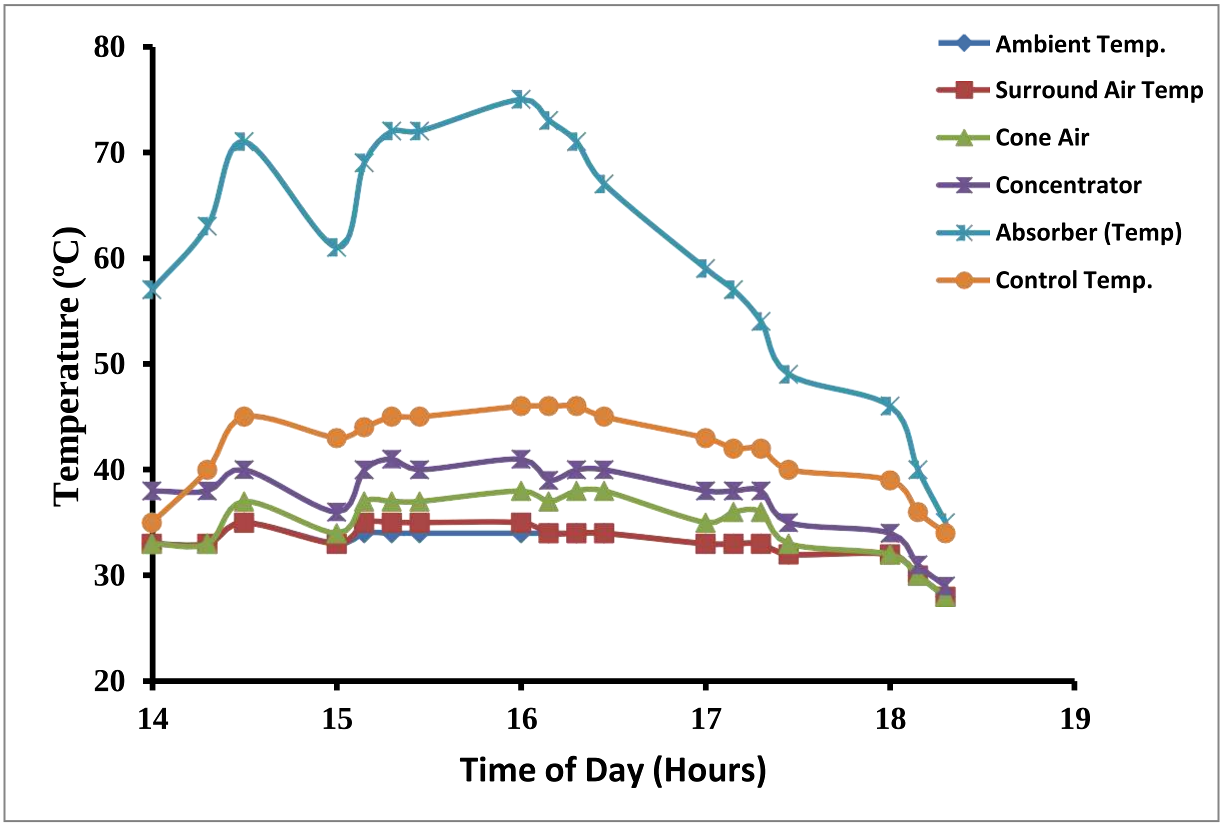

Figure 14: *Graph of Half Hourly Variations of the Temperatures of the Absorber, Control, Concentrator, Cone, Surrounding Air and Ambient Collector on day 4*

Figure 14 shows a close similarity with figure 13. The peak values of the absorber temperature of 75 ºC occurred at 16.00 hours and decreased to 34 ºC at 18.30 hours. The most favorable days for solar cooking are clearly shown in figs 12, 13 and 14. On these days, the absorber (focus) temperatures obtained varied from 70 ºC to 96 ºC which are good temperature for solar cooking.

Throughout the experimental period, the rating of students' attributes was also being conducted guided by a research question: **What is the mean rating of students' demonstration of generic and soft skills as they carried out the project?**

5. Instrument

Three research assistants who played supervisory role were ab initio issued structured five-point scale questionnaire with which to rate the extent to which students exhibited the skillson the instrument. The reliability coefficient of the instrument using Cronbach alpha reliability estimate had been established at .65. The instrument was used to rate the extent to which students demonstrated generic and soft skills as they carried out the project. A score of 5 was regarded as excellent, 4 (very good), 3 (good), 2 (fair) and 1 (poor).

Data were analyzed using mean and standard deviation.

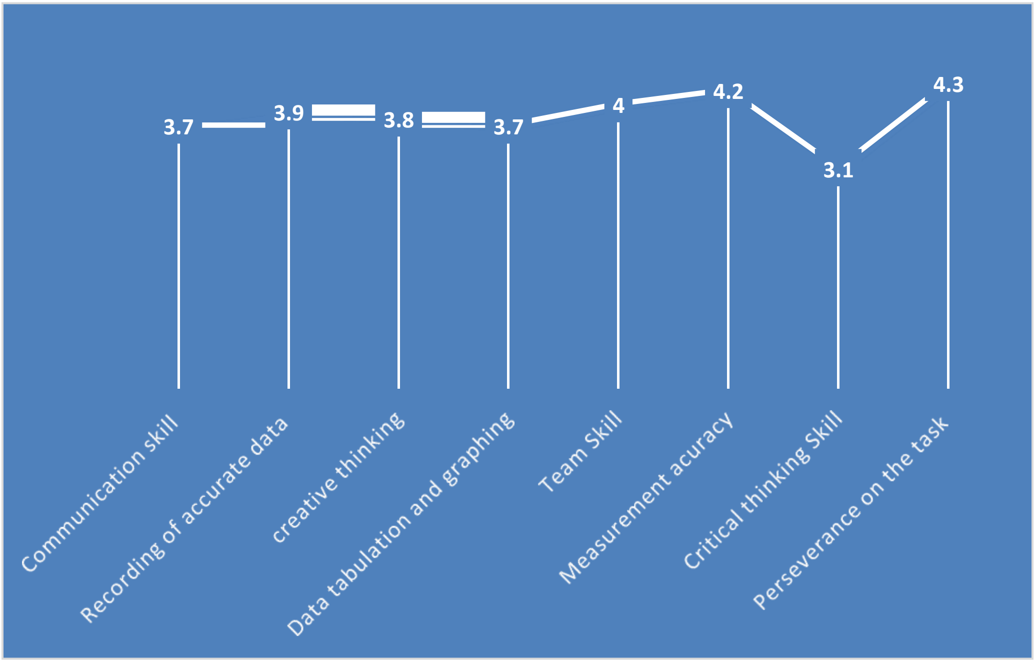

Figure 15: *Mean Rating of Students' Demonstration of Generic and Soft Skills*

Figure 15 shows the mean rating score of students' to stay on task to be 4.3; measurement skill, 4.2; team skill 4.0; ability to record accurate data 3.9; demonstration of creative skill 3.8;communication skill 3.7 and critical thinking 3.1. Overall, mean rating score of skills demonstrated by the students during the conduct of the project was good.

6. Discussion

Results from this study are in agreement with earlier studies such as Muhammad-Sukki, Ramirez-Iniguez, McEwin, & Clive (2015) who opined that to ensure higher efficiency, the collector should always be directed towards the incoming solar radiation from morning (east) to sunset (west). This explains why the maximum temperature values on the absorber were obtained at the peak periods from about 12.00 hours to about 14.00 hours. Maximum sunshine hour occurs within this time interval. However, the intermittent nature of solar radiation affected the performance of the solar cooker. The sudden appearance of rain cloud shielded the sun, thus deceasing the solar radiation reaching the solar concentrator. The period of this study if carried out during the dry season when solar radiation is very much available, the efficiency of the solar cooker will be very much enhanced. To avoid multiple reflections from the concentrator, its surface should be cleaned to remove dust particles on it which students may not be sensitive to.

Results of the mean ratings of students' skills give credence to project-based learning because the ability of the students to persevere on monitoring the temperatures of the absorber, collector, ambient, the control, the air within the concentrator aperture, the surrounding air using the mercury-in-glass thermometer; and the solar insolation using pyranometer over a period of four days could have been a consequence of their team work. In the team, they were able to discuss, construct their own meanings and interpret the readings at intervals, despite weather fluctuations. Hence, this study agrees with Tamim & Grant (2013) (and other supporters of PBL)on the claim that PBL promotes analytical, creative and critical thinking skills, since students demonstrated ability to tabulate and interpret data, drew relevant graphs and finally came up with meaningful conclusion on the project.

7. Conclusion

The study was meant to advocate for the implementation of a more proactive instructional model which has the capacity of fostering in learners, sustainable practices that will address in meaningful ways challenges facing rural Nigerians in this decade. The solar cooker which the students designed was used to boil eggs. This implies that classroom activity which engenders deeper learning can imbue in learners the knowledge transfer that helps them survive in a highly competitive, fast growing and market-driven society. Solar energy technology is a major sustainable practice that should be adopted in Nigeria today to better the lives of the rural people who continue to use wood for cooking because they cannot afford to buy cooking gas or kerosene. In addition, research has shown that burning fossil fuels is not only detrimental to health but it also leads to deforestation. Deforestation in turn leads to global warming and erosion. Consequently, alternative sources of energy should be made available for the well- being of people. The system of education should shift from traditional approaches to 21st century pedagogical approaches that will foster among learners, the competencies they need to survive inthe society after school even if they were unemployed in the public sector.

8. Recommendations

- Considering the relevance of PBL in connecting classroom learning to life outside and by addressing real world issues, teachers are recommended to take advantage of its applicability to build relationships with students in the school and with the larger community.
- Professional development for teachers should be highly encouraged to facilitate their interest and equip them with activity-based models. This will also promote better achievement in science- related courses especially in Physics and Chemistry. In addition, PBL may help both female teachers and female students to foster gender friendly learning environment that will enhance the increase of female enrolment in the science and engineering fields in higher institutions.
- Curriculum planners are by this study urged to take cognizance of the global worlds needs while drawing up curriculum for learners of this generation.
- Nigeria as a nation should be conscious of global trends in sustainability (environmental sustainability and sustainable education) and work hard towards achieving these by 2030. Most importantly the utilization of abundant solar energy which is free, clean, green and in exhaustible for the well-being of the average Nigerian in terms of provision of constant power supply has become very imperative.

9. Scope of Future Research

In the light of the findings of this study, possible further research recommended is as follows:

- Apart from solar energy applications, students at the same post-secondary level could be exposed to projects on other renewable energy technologies such as biomass, windpower, hydro power
- Replication of this study over a longer period of time than that which was available for this study could be undertaken especially in the usage of biomass. It could help the students appreciate better the benefits of PBL as well as fortifying them with sustainable knowledge for real life applications.

- Further studies are recommended whereby effect of inquiry and project based learning are integrated to foster higher order skills among learners within the context of contemporary issues in developing nations.

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