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Pathway to Higher Order Thinking with Learning by Design Pedagogy

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ABSTRACT

Purpose of the study: This research article talks about the Learning by Designing (LbD) pedagogy where students get engaged in small tasks which are hands-on, timed and in class. With evolution of Artificial intelligence (AI) in the teaching learning process it is important to develop strategies where students develop higher order thinking with unique projects and reduce temptations to rely on AI.

Methodology: Fifteen students engaged in a three-day design-based activity to monitor solar panel performance using temperature, light, and current sensors connected to an Arduino microcontroller. Unlike traditional demonstrations, this hands-on design task emphasized critical thinking, collaboration, and reflection. The Arduino controls all these sensors and allows quantifying the readings for aforementioned parameters, which can be displayed on a computer screen and finally stored.

Main Findings: This experiment is done by a group of students and their learning experiences are discussed. A mixed-methods approach was used: technical data analysis complemented by qualitative reflection and questionnaires assessing cognitive development. Findings indicate measurable improvement in analytical reasoning (87% of students), practical problem-solving (80%), and creativity through iterative prototyping.

Novelty/Originality of this study: This study proposes a Learning by Design framework integrating Arduino–IoT experiments in solar energy optimization to explore how such activities promote higher-order thinking, problem-solving, and academic authenticity in an AI-rich educational landscape. While many studies emphasize technical success, few have examined how such IoT-integrated, design-based experiments enhance cognitive and metacognitive growth.

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1. INTRODUCTION

Learning by Designing pedagogy is an educational approach that emphasizes the importance of hands-on, experiential learning and can be applied to strategize educational institutes and in companies. In this approach, participants are actively engaged in the design and creation of projects, products, strategies or solutions to real-world problems. With the advent of AI it is utmost important to strike a balance between the usage of AI tools for achieving academic goals and developing the essential skills for lifelong success. The rapid integration of AI in education has reshaped teaching–learning dynamics, offering efficiency while posing challenges to academic integrity and critical reasoning. Students increasingly rely on AI-generated solutions, reducing opportunities for analytical and creative engagement. Hence, educators must adopt pedagogies that strengthen originality, inquiry, and higher-order cognitive skills [1]. By designing and creating, participants learn by doing, and gain a deeper understanding of the concepts and skills they are studying [2], [3]. The focus of this pedagogy is on problem-solving, critical thinking, and collaboration, where participants work in teams on a defined problem, brainstorm for prototype solutions, and iterate and refine their designs; in this process, they develop skills in creative thinking, communication, and teamwork, as well as technical and design skills [4-6].

This pedagogy has been applied in a variety of educational settings, including K-12 schools, higher education institutions, and workplace training programs [7-9]. Studies have shown that in educational institutes, this pedagogy has been effective in improving students' motivation and engagement, as well as their knowledge retention and application of the material [10-12]. In the context of solar studies, Learning by Designing can be a powerful way for students to gain practical skills and knowledge in the field of renewable energy and optimization of solar power using Arduino can improve the efficiency, reliability, and sustainability of solar energy production while also reducing costs and advancing research and education in the field [13-18].

In the laboratory context, this study plays several specific roles that center on developing students' design skills, problem-solving abilities, and higher-order thinking. Students are challenged to design and construct a functional solar cell prototype using various materials and techniques, prompting them to investigate the scientific and engineering principles behind solar cells while experimenting with alternative designs. They are also guided to optimize solar cell efficiency under particular conditions such as varying light intensity or temperature which requires data analysis, the use of simulation software, and the exploration of different material configurations. Additionally, students work collaboratively to create solar-powered devices, such as charging stations or water purification systems, integrating their understanding of solar energy with other engineering principles, including circuit design and power management.

Throughout the process, they are required to upload intermediate drafts or annotated explanations, along with the final product, supported by schematics and Tinkercad circuit designs. Although previous research has independently validated both Learning by Design and Arduino-based experimentation, there is limited work combining these approaches to assess higher-order cognitive outcomes. Furthermore, few studies examine how authentic, design-driven tasks can reinforce academic honesty amid the growing reliance on AI. Therefore, this study aims to integrate Learning by Design pedagogy with an Arduino-IoT solar optimization project, examine its effects on students' analytical, evaluative, and creative skills, and evaluate its potential to promote self-regulated and authentic learning in AI-enhanced educational environments. At this juncture, it is crucial for educators to be proactive in adopting and disseminating such modified pedagogical approaches.

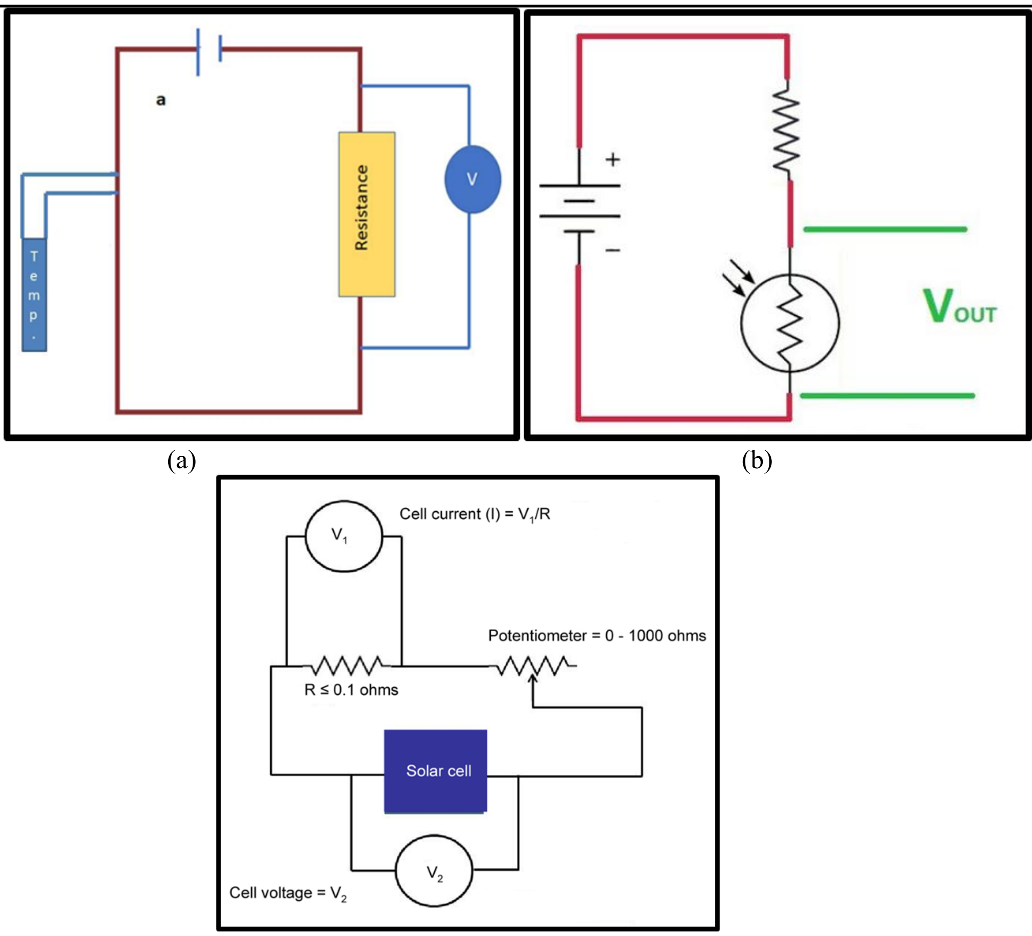
2. RESEARCH METHOD

To optimize the solar power, solar panel, Arduino UNO (Shown in Fig 1), DS18B20 (1-wire digital temperature sensor) LDR and current sensor are used and through programming produce the required outputs. The confirmations for the circuits and programming were done using Tinkercad software. Tinkercad software is a free, online 3D Design, 3D modelling, electronics and Coding program that builds STEM confidence by bringing project-based learning to the classroom. It is an excellent tool that allows us to simulate Arduino -based systems.

First, automated Solar panel circuits are designed and tested on Tinkercad and then used in designing the physical circuit using Arduino Board. It is an open-source microcontroller Board based on the microchip ATmega328P microcontroller and developed by Arduino. The Arduino UNO board has a range of features that make it ideal for prototyping and experimentation. It has 14 digital input/output pins, 6 analog input pins, a 16 MHz quartz crystal, a USB connection for programming and power, and a power jack. The Board is equipped with sets of digital and analogue input/output (I/O) pins that may be interfaces to various expansion boards and other circuits.

A descriptive, mixed-methods design was adopted to evaluate both cognitive and experiential outcomes of the LbD activity. The design combined quantitative measures (questionnaire responses) with qualitative evidence (reflection journals and instructor observations). The study involved 15 undergraduate Physics students from Maitreyi College, University of Delhi, selected via purposive sampling due to prior exposure to basic electronics. Students were divided into three collaborative groups of five.

The project followed the four-stage Learning by Design cycle: (1) Problem identification – understanding factors affecting solar panel efficiency; (2) Design – developing circuits with Arduino UNO, temperature sensors, LDRs, and current sensors, simulated on Tinkercad (3) Testing and iteration – recording real-time solar data for three days and refining circuits; (4) Reflection – writing individual learning journals and participating in group discussions. Schematic of Circuit diagrams which were implemented to measure temperature, light intensity and solar power on Tinkercad [19], using Arduino UNO are shown as in figure 1.



(a) (b)

(c)

Figure 1. Circuit Diagram of (a) Temperature Sensor (b) LDR (c) Solar cell

3. RESULTS AND DISCUSSION

The circuits were connected according to the individual component circuit to obtain desired results on Tinkercad and then physically as in Figure 2. The final circuit was made by combining all the components circuits.

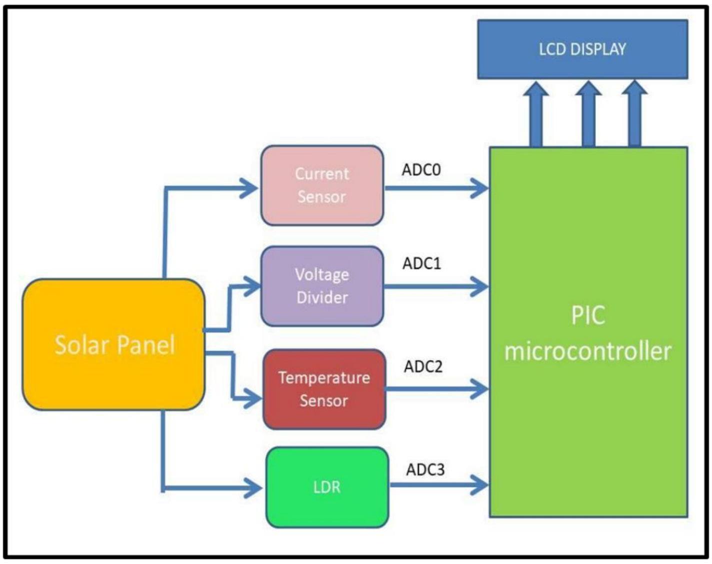


Figure 2. Block Diagram of designed circuit for optimization of solar energy for automatic control using Arduino UNO

The voltage that has to be measured is sent to the analog pin of the Arduino, where the Arduino reads and interprets the voltage value. A voltage divider circuit (As shown in Figure 3(a) and 3(b)) has been made here to ensure that a voltage of more than 5V is not sent to the analog pin otherwise there are chances of the Arduino getting destroyed.

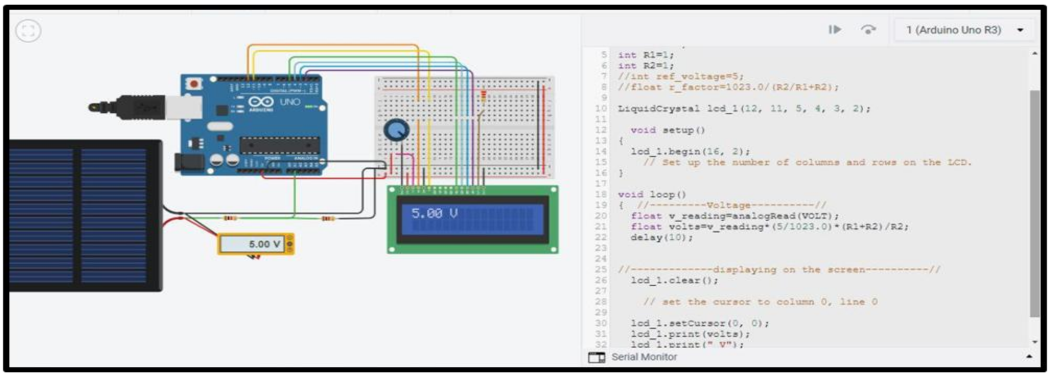


Figure 3. (a) Tinkercad circuit measuring voltage produced by Solar cell

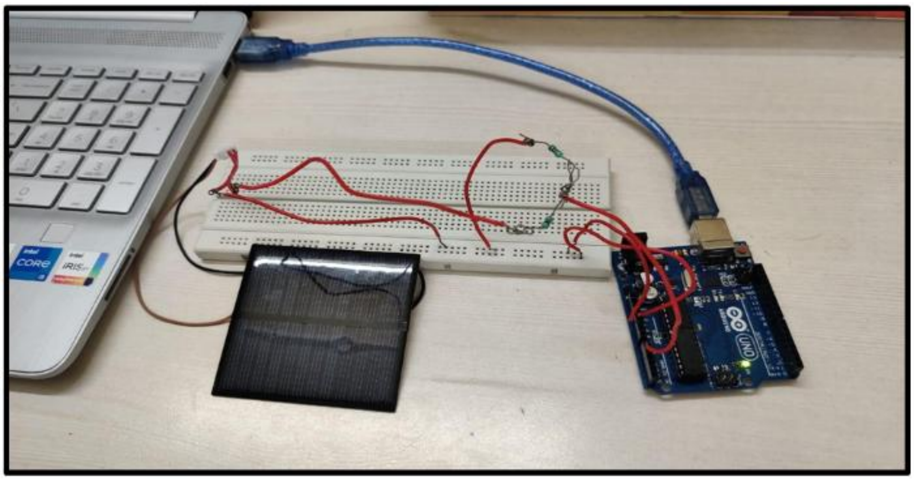


Figure 3. (b) Voltage divider circuit measuring voltage produced by solar cell

LDR (light dependent resistor) also called photoresistors are responsive to light. There is an inverse relation between the resistance of LDR and light intensity. As light intensity increases the resistance of LDR decreases and hence more current starts flowing. This current is measured and hence the light intensity can be known. Circuits designed on Tinkercad and on real Arduino Board are shown in Figure 3(c) and Figure 3(d).

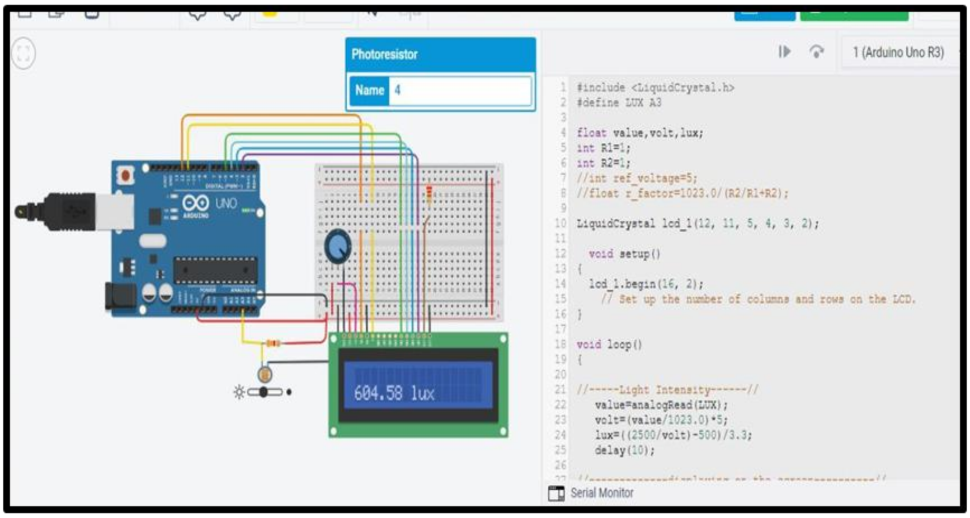


Figure 3. (c) Tinkercad component circuit of LDR

A temperature sensor measures any physical change in the temperature. The circuit designed on Tinkercad is shown in Figure 3 (e). To make Circuit physically, First of all, circuit has been designed on Arduino Uno and interfaced to the laptop through programming. In the program we have used two inbuilt libraries named Onewire.h and Dallastemperature.h. [20], [21]. The designed circuit is shown in figure 3 (f). The main function here runs continuously and readings are displayed in a loop until it is stopped manually, hence the values are easy to read and updated regularly [22].

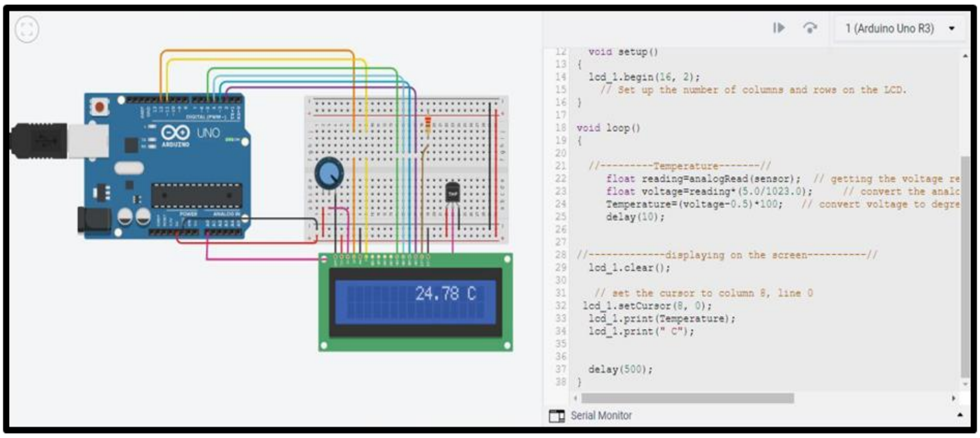


Figure 3. (e) Tinkercad component circuit of Temperature Sensor

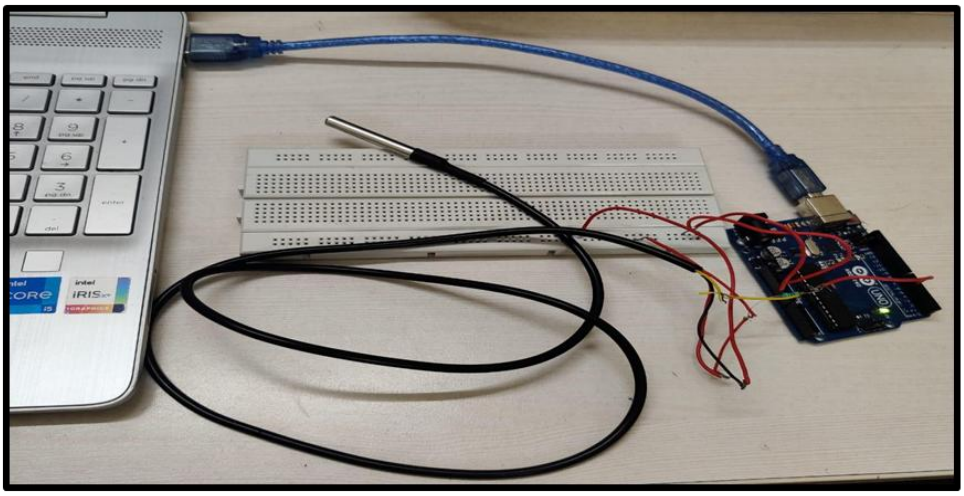


Figure 3. (f) Temperature sensor measuring the surrounding temperature

Combined circuits designed on Tinkercad and with physical components on Arduino Board are shown in figure 3(g) and 3 (h).

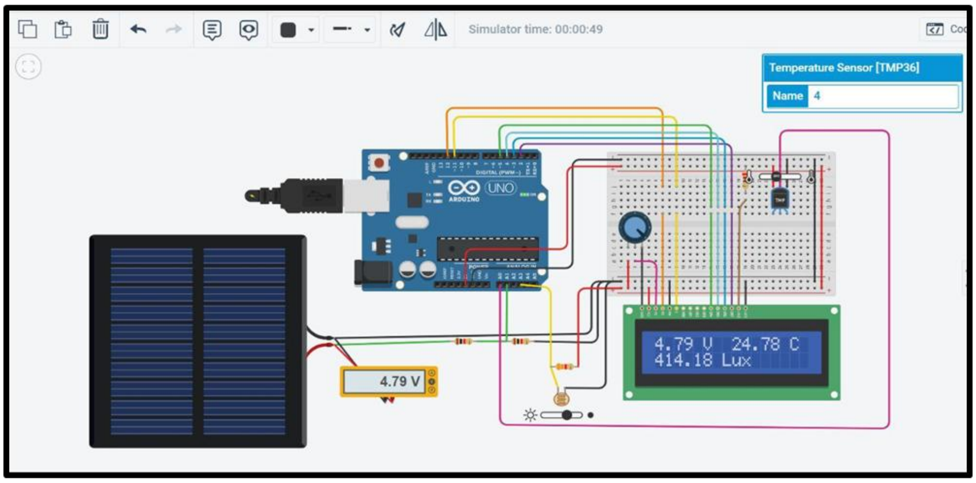


Figure 3. (g) Combined Tinkercad circuit

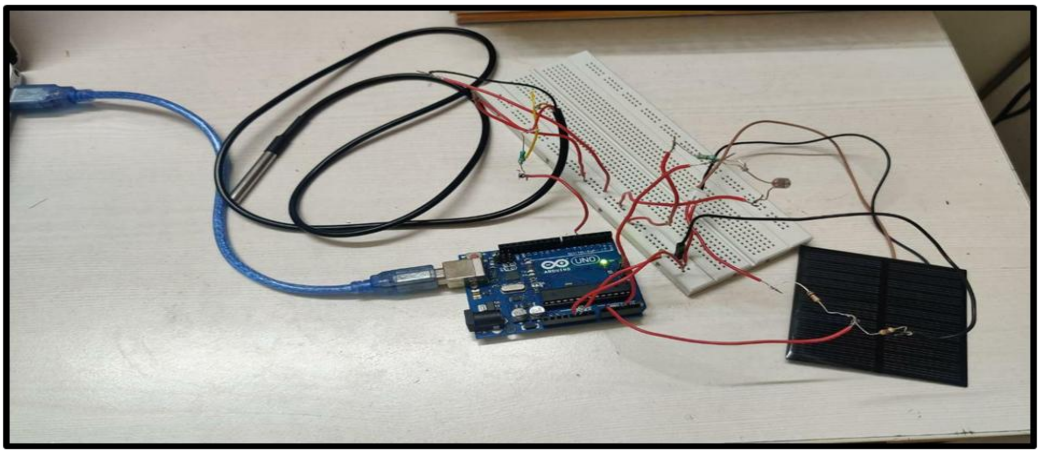


Figure 3. (h). Complete setup designed on Arduino Uno Board

Output for voltage value, Temperature and light intensity obtained on Computer Monitor of Combined circuit designed on Arduino Board are shown in Figure 4(a).

The output values of the temperature sensor are both in Fahrenheit and centigrade and intensity is displayed in lux [23]. Data of solar cell parameters are recorded over three days using the automated system at different time instants and arranged in tabular form in table 1. Results (Voltage Versus Time, Temperature Versus Time and Light intensity Versus Time) are compiled and shown by bar graph in figures 4 (b), (c) and (d).

From the Bar graph, it is observed that the value of highest voltage recorded in 3 days was 7.41 Volts at approx 2:30 pm and at that time light intensity was 4154 lux. Minimum voltage value is found to be 3.35 volts at 4:00 pm with light intensity value 658 lux. Maximum current was observed at around 1.00PM to 2.00PM and minimum at around 4PM (bar graph is shown in figure 4 (e). Maximum temperature was observed at around 1.00PM and minimum at around 4.00PM. Power was calculated by taking an average of the data over three days. And it is found to be maximum around 2.00PM to 2.30PM and minimum at around 4.00PM. Power generated versus time graph is shown in figure 4 (f). From the figure, the maximum power generated is ~20mW.

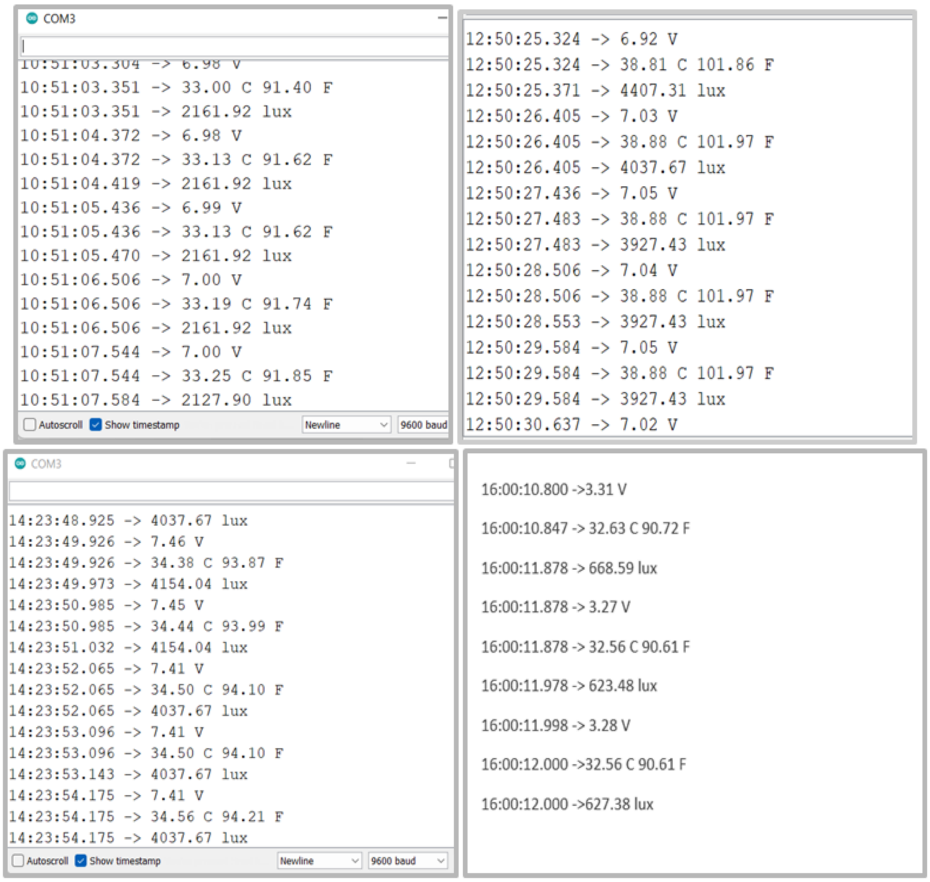


Figure 4. (a) Screenshots of output of sensors used in circuit

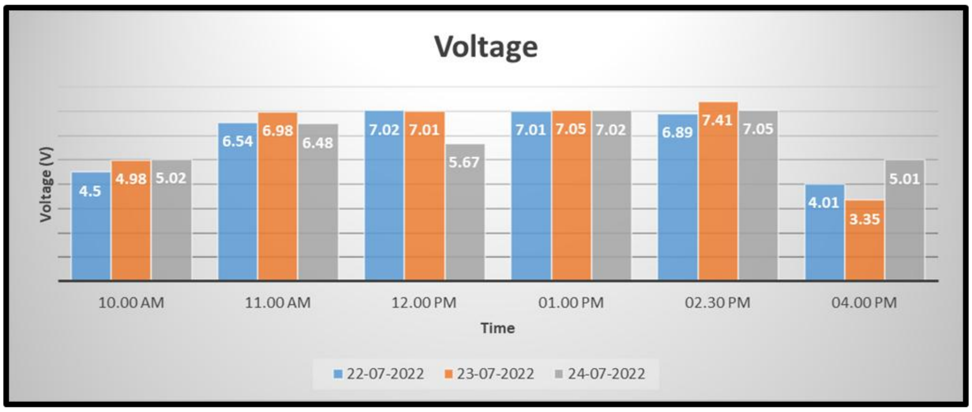


Figure 4. (b) Bar graph for voltage versus time

Table 1. Data of solar cell parameters recorded over three days using the automated system

Time	Voltage			Light Intensity (Lux)			Temperature (°C)		
	22-07-2022	23-07-2022	22-07-2022	23-07-2022	24-07-2022	24-07-2022	22-07-2022	23-07-2022	24-07-2022
10.00 AM	4.5	4.98	31.5	32.9	32.4	5.02	799	823	843
11.00 AM	6.54	6.98	32.4	33.13	30.75	6.48	2500	2161	2520
12.00 PM	7.02	7.01	37.1	38.2	34.78	5.67	3205	3012	1380
01.00 PM	7.01	7.05	37.76	38.88	37.34	7.02	2843	4037	4121
02.00 PM	6.89	7.41	33.87	34.56	38.56	7.05	3312	4154	3371
04.00 PM	4.01	3.35	31.12	33.38	33.12	5.01	704	688	779

Time	Current (mA)			Power (mW)			Average
	22-07-2022	23-07-2022	24-07-2022	22-07-2022	23-07-2022	24-07-2022	
10.00 AM	2.5	2.5	2.5	11.25	12.45	12.55	12.08333
11.00 AM	2.5	2.5	2.5	16.35	17.45	16.2	16.66667
12.00 PM	3	3	3	21.06	21.03	14.61	18.56667
01.00 PM	3	3	3	21.03	21.15	21.06	21.08
02.00 PM	3	3	3	20.67	22.23	21.15	21.35
04.00 PM	2.5	2.5	2.5	10.025	8.375	12.525	10.30833

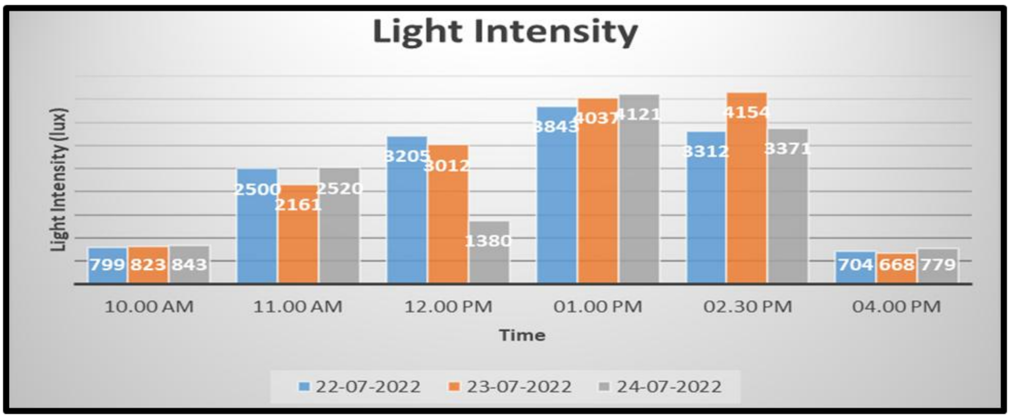


Figure 4. (c). Bar graph for light intensity versus time

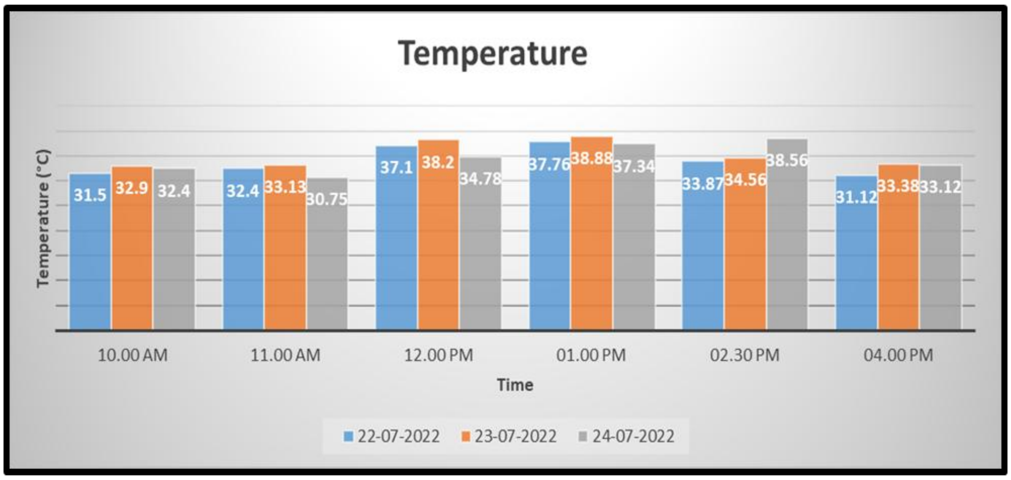


Figure 4(d). Bar graph for temperature versus time

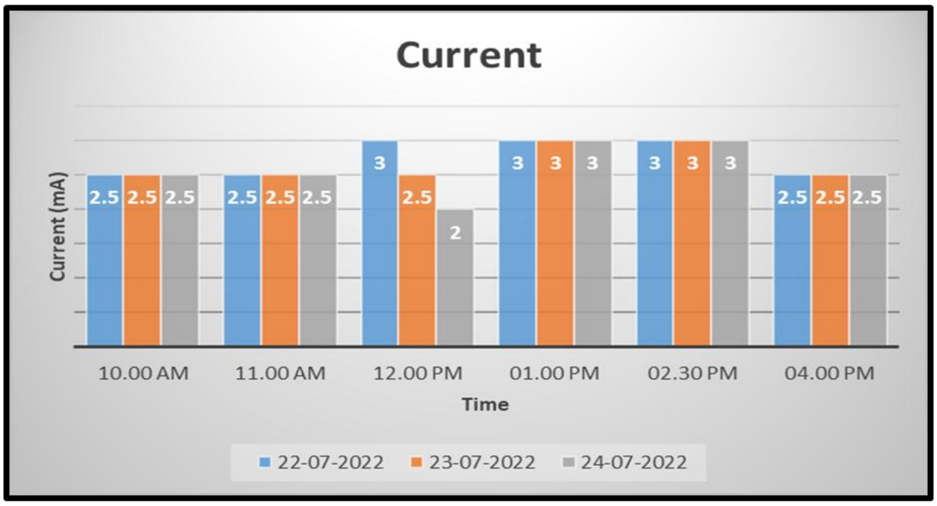


Figure 4(e). Bar graph for current versus time

Note that the observations were taken during monsoon. So, the weather conditions were highly varying.

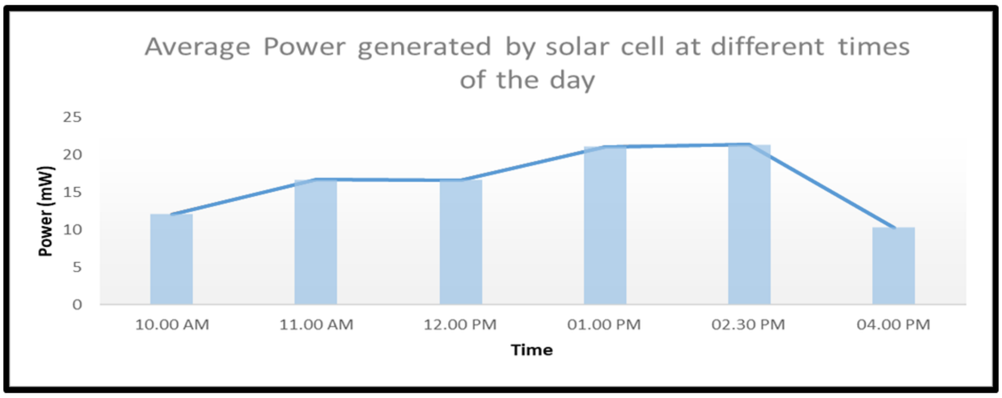


Figure 4(f). Graph for power versus time

The results presented in this report demonstrate the capabilities of the design. The device has strong potential value in higher education as of its low cost and high efficiency [24-25]. This device can also be used from different educational approaches, such as model based inquiry approach or maker approach. The design process helped connect theoretical physics to real-world applications while strengthening teamwork and independent reasoning [26]. Qualitative assessments through reflection journals were done and some of the students elaborated their learning experiences and are given below.

The students extended their approach of learning through this work. There were few responses with implications as following:

1. **This piece of work helped to correlate the theoretical knowledge to the practical realization which provides better understanding of the electronic devices.**
   This statement embarks oneself to Higher-order thinking which means the ability to connect, manipulate, and apply information in new contexts. It emphasizes understanding relationships between ideas, making judgments based on evidence, and generating original solutions
2. **With an immense growth in utilization of solar power, with an insight like this would help explore job opportunities in this field.**
   It clearly reflects Metacognitive Development. Students not only learn technical content but also reflect on their own decision-making, improving metacognitive awareness which is a hallmark of higher-order thinking.
3. **Arduino and Tinkercad are two powerful tools that can enable us to enter the world of electronics and engineering. These tools offer endless possibilities for creating and innovating.**
   This statement infers that integration with Design-Based learning which provides the intellectual roadmap for transforming inquiry into deep, sustained understanding. Students are trained in Higher Order Thinking and are better prepared to navigate complex societal, scientific, and professional challenges where memorized information alone is insufficient.

Connection between Bloom's Taxonomy and the Solar Panel Learning by Designing

The solar panel group activity naturally aligns with all six levels of Bloom's Taxonomy. Each stage of the activity encourages a specific level of cognitive engagement, moving from foundational to complex intellectual tasks [24]. Given below is Table 2 highlighting the Bloom's level, learning experience and learning Outcomes.

Table 2. Highlighting the Bloom's level, learning experience and learning Outcomes

Bloom's Level	Student Activity in Solar Panel Project	Skill Developed
Remember	Recall basic solar energy concepts (sunlight, photovoltaic effect, energy conversion) Basic circuit making using bread-board	Knowledge acquisition
Understand	Tinkercad helps students understand the working of circuits using software before realizing it practically.	Comprehension and conceptual clarity
Apply	Design circuit with Arduino and different sensors, Use formulas like voltage divider rule and Power to calculate panel efficiency,	Application of principles to real-world contexts
Analyze	Compare the power generated across the solar panel over three days. Analyze placement strategies to improve the output.	Analytical reasoning and evaluation of data
Evaluate	Assess which time of the day is most suitable. Discuss variables (temperature, light intensity) affecting the performance[27].	Critical judgment and decision-making
Create	Design and construct a functional solar model (charging station, or power system) and present implementation proposals [28].	Innovation and synthesis of ideas

Findings indicate that by Learning by Designing IoT integration significantly enhanced students' higher-order thinking, consistent with Bloom's taxonomy domains [29]. Through iterative design and data interpretation, students demonstrated analytical reasoning identifying variable relationships between light intensity and voltage output [30]. Reflection journals and questionnaire responses revealed that 87% of students reported improved analytical skills, while 80% expressed higher confidence in applying theory to practice. These results are unique as it uses reflection rubrics to assess cognition more rigorously and includes pre/post cognitive assessments. The newness in this model is that it offers a low-cost, scalable framework for STEM institutions to integrate higher-order thinking into laboratory learning. However, the limitations encountered are expanding to larger cohorts for scalability and integrating variety of LbD activities to cover the curriculum

4. CONCLUSION

Here we propose a route of learning by designing which caters to the growth in higher order thinking and improved cognitive skills. The integration of Learning by Design with IoT (Internet of Things) tools offers a low-cost, scalable model for cultivating higher-order thinking and academic integrity in the era of Artificial Intelligence. In this work, fifteen undergraduate Physics students divided into three collaborative groups of five have demonstrated the use of a solar panel compatible with an Arduino micro-controller to measure key parameters such as voltage, current, temperature, and light intensity that are critical for studying the efficiency of a solar cell. This pedagogy of LbD helped fostering higher-order thinking a crucial distinction for developing intellectual independence and creativity in any field. This study provides empirical evidence that combining Learning by Design pedagogy with Arduino IoT solar experimentation enhances higher-order thinking and academic authenticity. Student reflections and surveys showed 87% improvement in analytical reasoning and 80% gains in evaluative and creative confidence. This study also reveals that critical and higher order thinking is encouraged when students are engaged in such real life problems. It maintains academic integrity while avoiding over reliance on AI generated content. Learning by Designing sets a boundary between original student work and algorithm-produced assignments leading to academic honesty. It is the time where we, educators, are forced to rethink the methods of teaching-learning and shifting towards more holistic learning by design pedagogy to uphold integrity. It is suggested for further research to formulate techniques where comparing design-based with AI supported learning approaches could be done .

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