Development of Thermoelectric Generator Kit Inquiry-Based Lessons and Activities for Malaysia Primary Students

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Abstract
Parallel to the era of the Industrial Revolution 4.0 (IR 4.0), the Standard Based Curriculum for Primary School (KSSR) Science subject-based teaching and learning method urgently need be revised. The new curriculum should be promoted the student-centred instruction with a greater emphasis on problem-solving, project-based assignments, subject updates, and formative evaluations. Based on the physical science theme of the Standard Five Science curriculum, which comprises of four sub-topics including energy, the nature of light, electricity, and heat. There is the possibility of combining three subtopics (energy, electrical, and heat) into a single subtopic known as energy harvesting from the environment's waste such as heat waste and mechanical energy waste (eg. vibration waste). A development of thermoelectric generator kit for teaching and learning about energy harvesting from heat waste to electrical energy will be based on a simple experiment setup. At the end of the experiment, students will be instructed on energy harvesting from the environment that satisfies the world demand for energy without placing them at risk of expiration and may be reused.

Keywords: Energy harvesting, Thermoelectric Generator, Inquiry-based lessons and activities

1.0 Introduction

On September 25, 2015, at the United Nations summit for commitment to eradicate poverty and achieve sustainable development by 2030 worldwide, the UN's report of Transforming our World: the 2030 Agenda for Sustainable Development was presented. The agenda is comprised of 17 Sustainable Development Goals (SDGs), which are aimed at achieving sustainable development with the purpose of improving the globe. Goal 7 of the Sustainable Development Goals aims to guarantee that all people have access to energy that is modern, dependable, affordable, and sustainable. Awate, S. (2017) demonstrated the teaching of the sustainable development goals by engagement global school. Ryokai, K., et al. (2014) conducted an energy harvesting camp for kids at a school in Toronto, Canada, where they used wearables that harvested energy.

Therefore, an introduction of energy harvesting sub-topic by means of a thermoelectric generator is an integration of the teaching and learning process into the Industrial Revolution 4.0 for education. Since the independence of Malaysia, students have been taught about renewable energy, however energy harvesting is an alternative method for environmental sustainability that is not emphasised in textbooks. As a result, students are will be exposed and integrated with the subtopics of heat, energy, light, and electricity in the context of energy harvesting for environmental sustainability utilising a thermoelectric generator at school.

Energy, light, electricity, and heat are subtopics of the Standard 5 Science Syllabus in public primary school. The majority of primary educators rely on textbook exercises for their teaching and learning lessons. These sub-topics are not related to each other in the textbook, and there are fewer activities. The integration of these subtopics resulted in the introduction of a new subtopic: energy harvesting from environmental waste, such as heat waste and noise, into another type of energy as shown in Figure 1.

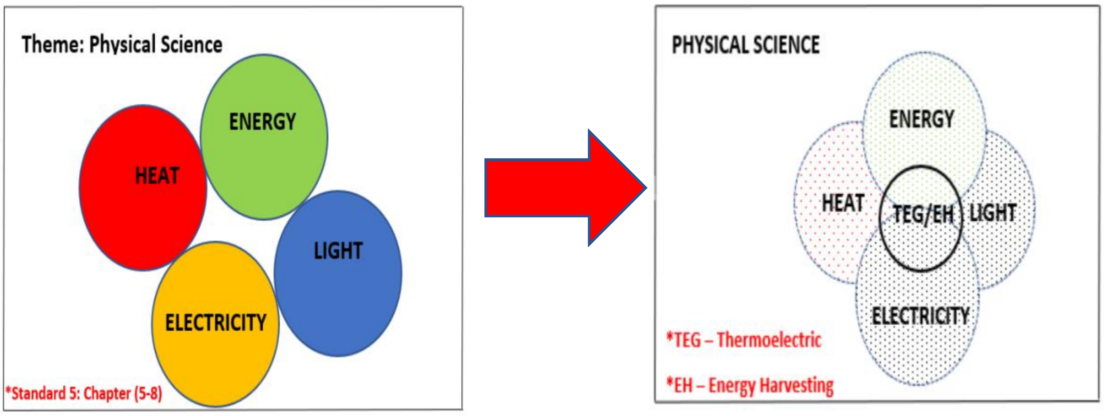

Figure 1: Integration of energy harvesting using Thermoelectric

2.0 Literature Review

The Seebeck effect is the direct electrical conversion of temperature variations. Thomas J. Seebeck, who discovered the phenomena in 1821, is honoured by the moniker "Seebeck effect." Seebeck observed that an electromagnetic field was generated when a loop composed of two different materials was heated on one side. Thomas J. Seebeck (1821) observed that the electromagnetic field intensity, and consequently the voltage, is proportional to the temperature differential between the hot and cold sides of the material.

Vassilenko, V., et al. (2016) presented tests to compute the power that can be generated from chest motions during breathing and from feet movements during walking, etc. as an exciting topic for engineering education programmes. Hadas, Z., and Singule, V. (2010) introduced "Energy Harvesting" as a new subject for mechatronics education in the area of power sources for autonomous mechatronic applications. Xingwei Wang and Liang Guo (2021) presented a student-centered curriculum model on Renewable Energy Sources (RES) since RES is a crucial solution to the energy problem, and developing talents with essential skills and traits has become a crucial component of our entire energy strategy. Afkar, M., et al. (2019) provided a novel plan for introducing renewable energies through a teaching technique based on narrative of a student social action in renewable energy education. Bosman, L. B., & Chelberg, K. A. (2019). Integrating context and authenticity in the STEM academy for renewable energy education to enhance pre-college involvement. Sie, T. N. et al. (2021) created Thermoelectric energy harvesting for lighting LEDs with tealights in rural Sabah and Sarawak communities in Malaysia.

3.0 Methodology

A setup for an experiment involving a thermoelectric generator that may be readily and simply created by the teacher or students, as shown in Table 1 for the list of materials and components used for the full setup. The deployment of inquiry-based TEG Kit lessons and activities is separated into three phases: - First Phase: Set Induction, Second Phase: Student Response, and Third Phase: Experimental Setup Session.

Table 1: List of materials and components

Item	Name	Unit
a	Thermoelectric Generator Module (TEG)	2
b	Digital Multimeter	1
c	Bunsen Burner	1
d	Tripod stand and ceramic wire gauge	1
e	Crocodiles clips	1
f	LED	1
g	Miniature D.C Fan	1
h	Buzzer	1
i	Thermometer	1
j	Heatsink	1
k	Wax candles	1

The student-centred experimental design with application makes learning more enjoyable and significant. Consequently, student motivation and interest in learning energy harvesting are increased. To tie the science to its application, namely the employment of thermoelectric generators in everyday life for environmental sustainability, in the context of energy harvesting as an application.

3.1 First Phase: Set Induction

To illustrate the concept of energy harvesting prior to the session, the instructor will play a video demonstration of energy harvesting applications and thermoelectric generator use. The students' comprehension of the concept of energy harvesting is evident after viewing the video. (Video link:- https://youtu.be/30iwZIXMB-o and https://youtu.be/YhynSkFlJOs).

3.2 Second Phase: Student Feedback

After viewing the video and demonstration of the thermoelectric generator (TEG) module, the students will be asked to explain why the TEG generates energy anytime heat is present on the module. Then, the teacher instructs the students to use a lighter to heat the bottom portion of the TEG module and to observe the output voltage from the multimeter, which involves the principle variations in temperature, i.e., "hot region and cold region." (Note: Most students, after figuring out the answer, will ask permission to examine and touch with the thermoelectric generator module, TEG).

3.3 Third Phase: Experimental Set-up Session

The apparatus utilised in the experiment is comprised of two elements. The first element to connect a single TEG module to a hot source with the help of a Bunsen burner, as shown in Figure 2 (a) and (b), and then measure the output voltage with the circuit open. It is necessary to repeat experiment by using two TEG modules that are connected in series. The result of the experiment as shown in Table 1 (single TEG module) and Table 2 (two TEG modules connected in series) respectively where the output voltage delivered in open circuit.

The final part of experiment is an application where the student is required to investigate how a TEG output can be used to power a variety of electronic components, including a digital clock, an LED, a DC fan, and a buzzer as shown in Figure 2 (c).

Figure 2: (a) TEG module, (b) Experiment Setup, (c) Open-Circuit with measurement and application test

4.0 Findings and Discussions

Table 1 and Table 2 shown the collection data of experimental setup using single TEG module and two TEGs module connected in series circuit. Then, the experiment results are depicted in graph of time versus temperature and output voltage as shown in Figure 3.

The highest harvested output voltage of using single TEG module is about 2.28 V within 9 minutes whereas using two TEGs connected in series circuit is harvested about 3.25 V at 9 minutes. The connection of series circuit using two TEGs module are approximately 2 times greater than that a single TEG module. Based on Kirchhoff's voltage law for series circuits, this experiment has proven that the output voltage of TEGs connected in series is approximately double value of the harvested output voltage using single TEG module. Due to the inhomogeneous distribution of heat radiation between the two TEG modules, the series connection yields resulted the values are approximately 1.5 times lower than theoretical result using two TEGs module. The temperature of TEG module which higher than 100 °C provide good differences of temperature, ΔT as required by Seebeck's effect to achieve optimum harvested output voltage.

At the end of the experimental setup, the students are observed the harvested electricity from TEG which its powered an application using digital clock, buzzer, an LED and miniature D.C Fan as shown in Table 4.

Table 2: Output Voltage using single TEG Module

Time/ minute	Temperature / °C	Output / V
Intial	26.0	0.20
1	35.0	0.50
2	46.0	0.6
3	56.0	0.78
4	68.0	1.08
5	78.0	1.26
6	80.0	1.35
7	85.0	1.80
8	90.0	2.09
9	95.0	2.28

Table 3: Output Voltage using two TEG Module

Time/ minute	Temperature / °C	Output / V
Intial	26.0	0.35
1	35.0	0.60
2	46.0	1.08
3	56.0	1.19
4	68.0	1.58
5	78.0	1.79
6	80.0	2.05
7	85.0	2.35
8	90.0	2.85
9	95.0	3.25

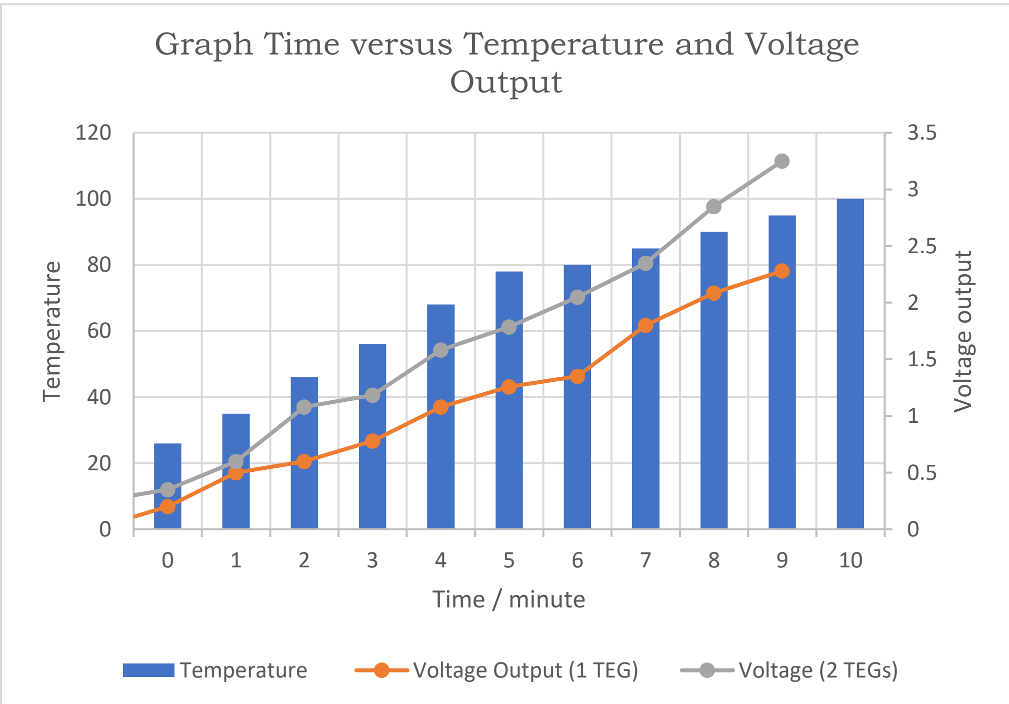

Figure 3: Data of Graph Time versus Temperature and Voltage Output

Table 4: Application based on student observation

No.	Apparatus	Observation
1	Digital clock	Its show the digital clock is operating when output TEG is connected in series.
2	Buzzer	The buzzer generated the 'buzz' sound when connected in series with TEG
3	An LED	The LED is powered and shine light when connected in series with TEG
4	Miniature D.C Fan	The LED is powered and shine light when connected in series with TEG

5.0 Conclusion

As a conclusion based on the development of a thermoelectric generator kit with application, the results of the experiment setup indicated that student-centred teaching and learning makes learning more pleasurable and meaningful. Thus, it improves student motivation and interest in energy harvesting, a similar issue with the United Nations Sustainable Development Goals (SDG:7) to encourage universal access to affordable, sustainable, and contemporary energy. This TEG Kit with applications demonstrates that the usage of thermoelectric generators can harvest 3.25 V using two TEGs and 2.28 V using a single TEG, which is sufficient to power LEDs for lighting, DC motor fans, and buzzers for environmental sustainability in energy harvesting.

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