Finite Element Analysis (FEA) in Electronics Devices and Photonics through Process Oriented Guided Inquiry Learning (POGIL)

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***Abstract*—Advance and complex mathematical skill such as finite element analysis are traditionally required to the understanding of electronics devices and photonics applications. Unless the students want to further their studies in theoretical field using complex calculations, students are offered an alternate learning skill such as POGIL by using software simulation packages with embedded FEA to help them visualize the abstract of photonics theories. Students were allowed to modify the original template given in the package, but in the learning process, they have to answer several guided questions in the activity specified. We presented two studies: Thermo Photovoltaic (TPV) cell and Acoustic Levitator (AL), prepared by two groups of third year physics students using COMSOL software and POGIL. As a result, students were able to complete their activities with a new skill of a standard researcher.**

***Index Terms*— Acoustic Levitator (AL); COMSOL; POGIL; Thermo Photovoltaic (TPV) Cell.**

I. Introduction

Generally, teaching and learning for content of microwave engineering focused to calculate, analyze and to design microwave circuits and often perceived as highly mathematical and difficult to comprehend [1].The use of standard industry software simulation packages to better understanding of photonic device and waveguide design is explored and students managed to visualize the abstract photonics electromagnetic concepts and theory [2]. Process Oriented Guided Inquiry Learning (POGIL) [3] is based on learning cycle which include exploration, concept formation and application [4]. Generally in POGIL class, the instructor does not lecture [5]. The instructor will act as a facilitator rather than as being a source of information.

We have experienced using POGIL in Discrete Mathematics [6] and for previous semester, we implemented POGIL for third year physics student in Finite Element course. During the semester, we assigned 14 groups which consist of four different members every week, so that each member will experienced a different role with a different set of members. Roles provide multiple perspective and motivate all group members to contribute [7].). We have 2 hours POGIL activity in class, then each group need to complete the activity outside class before they could attend another 2 hours of presentation class in that particular week.

In this paper, for the first part, we present POGIL in class activities: exploration, concept formation and applicaton followed by results and discussion about Thermo Photovoltaic (TPV) cell and Acoustic Levitator (AL) studies by two groups of students. We conclude our finding in the last part of this paper.

II. Exploration

COMSOL Multiphysics is a finite element analysis (FEA) solver and simulation software for various physics and engineering applications. Students were instructed to explore COMSOL Multiphysics software under electrical package in the first hour of POGIL activity. In this package, there are AC/DC, RF, Wave Optics, Ray Optics, MEMS, Plasma and Semiconductor modules. Students have to decide which module they would like to learn and followed the instruction provided in the sample module. During this activity student should also looked at the theoretical and equations involved in the particular sample. Students should follow all the instructions given by the template of chosen module.

III. Concept Formation

For the second hour of POGIL activity, student needs to answer the following questions:

1. What is the modification that they want to do in the module that they have followed through?
2. Why did they want to modify the original model or sample?

IV. Application

In this part of POGIL activity, students need to do the simulation outside formal class based on the modifications that they have decided. Here teamwork was crucial. There will be no instructor. They need to decide who will be the leader, the programmer, the recorder and the presenter and worked as a team. They also need to seek more literatures for the theoretical part which include the equations involved and the articles they need to review. There were another 2 hours of class during the week and the groups presented their findings. Here, the instructor will act as a participant and asked several questions.

V. Result And Discussion

We detailed the activities outcome of two groups.

A. The First Group

The first group investigated the effects of geometry structure of Thermo Photovoltaic (TPV) cell on its efficiency. TPV cell is a device that implement photovoltaic phenomenon that is originally used by PV cells that harvest solar power, but instead using the sun as the only heat source, it can also uses another certain heating material that is classified as the emitter component, which can give off continuous thermal energy for a fraction of which the sun can provide in a daytime. Photovoltaic phenomenon is the event of which an electron in a material is excited from the valence band to the conduction band of that material by absorption of incident photons. The material can later conducts electricity as it gains concentration of charge carrier and conducts the carriers as photocurrent. The chance of a photon can be absorbed by an electron is dependent on the wavelength of the photon. The requirement for that to occur is the wavelength of the photon must be equivalent to the energy gap of the material, or else, the absorption will not occur.

For a normal TPV cell, the range of working radiation produced by the emitter is between the near-infrared (near-IR) and IR frequency. In this event, PV cells can convert some of the photons given off among the phonon radiated in IR frequency. These denotes the first of many obstacles in peaking the efficacy of TPV cells; the common source of radiation in TPV cells itself is not fully convertible for electricity generation. And then there comes an incident photon with energy $hv \geq E$, adding to more problems already at hand. This is because the excess energy of the photon absorbed will contribute to unwanted heating of the cell. At elevated temperatures, the radiation can melt off the component.

Theoretically, to maximize heat conversion into electricity, the PV cell is ought to be set at every point facing the emitter. But this would mean extra PV cells per TPV system, and this is not a cost effective solution. The solution to that is to keep the count of PV cells in an "affordable" amount, while the heat loss by stray beam can be diminished by employing strategically-positioned mirrors to reflect the beam back to the emitter; 1) by doing this, the radiation that is bounced back can gain thermal energy as it approach the emitter region, thus reducing the number of low energy photons that come in contact with the PV cells, 2) the focusing of heat to the emitter, let the wave propagates in a new direction until it escape the "mirror-emitter" beam trap into another surface. This gives probability of photocurrent generation to the beam, which originally would go to waste.

The efficiency; the ratio at which the heat emitted is converted into electricity by photovoltaic (PV) cell is dependent on a lot of variables. One of which is just as crucial as the others; the geometry factor of the TPV cell. Based on the template structure from the model library in Figure 1(a), the modification were made in Figure 1(b) and 1(c). Figure 1(b) showed extra mirrors and extra PV cell while Figure 1(c) showed the extension of Figure 1(b) with the emitter diameter increased from 0.016m to 0.021m in radius. In each of the design, the constant and expressions specified were kept unchanged, so any change in the data can be credited fully to the geometry factor.

Figures 2(a), 2(b) and 2(c) showed contour plots with maximum heat recorded at 1579.46K, 1578.172K and 1974.082K, respectively. The group inferred that Figure 2(c) had the highest and operable thermal energy source where functioning temperature of common emitter is ~1800K.

The group mentioned that the streamline plot enabled them to observe the total heat flux inside the chamber of TPV cell in Figure 3(a), 3(b) and 3(c). From the plots the heat flowed inside the chamber and then distributed to any point in the TPV cell. With these plots, the efficiency of mirror formation could also be determined and the heat loss at each mirror could also be pointed out. Figure 3(a) and 3(c) had 20 lines of heat flux, representing the major routes of heat flow, while Figure 3(b) had only 19 lines. The group deduced Figure 3(b) had poor heat distribution. Further observations indicated that there was an inefficient radiation in Figure 3(c) as the heat flux line was inside the emitter and was not propagated to the exterior of the emitter component. From this aspect, the group believed that the template design was actually the best design as compared to the modified design model.

For the line graphs of electrical output power vs. temperature (point in the design was taken at a point just on the surface of the inner boundaries of a PV cell) at Figures 4(a), 4(b) and 4(c), the graphs depicted that the 1st modified design in Figure 4(b) was the most efficient TPV cell. The electrical output power was peaked at T = 1800 K at more than $3x10^5$ W/m^2 power generated. The other two designs both peaked at T = 1600 ~ 1700 K with electrical power $\approx$ $3x10^5$ W/m^2. From this scenario, one plausible deduction that can be established was that different temperature distribution between the designs and another, as clearly stated, was related to mirror formation as visualized in previous plot. Most of the line plotted representing heat flux which also represented the radiated wave fall on the surface of PV cell compared to the other designs. This group concluded that this condition was crucial for generation of electricity as the photons have to collide with the electrons inside the PV diodes on the wall of the chamber. Any heat flux on the inner boundaries of the insulation was considered energy waste.

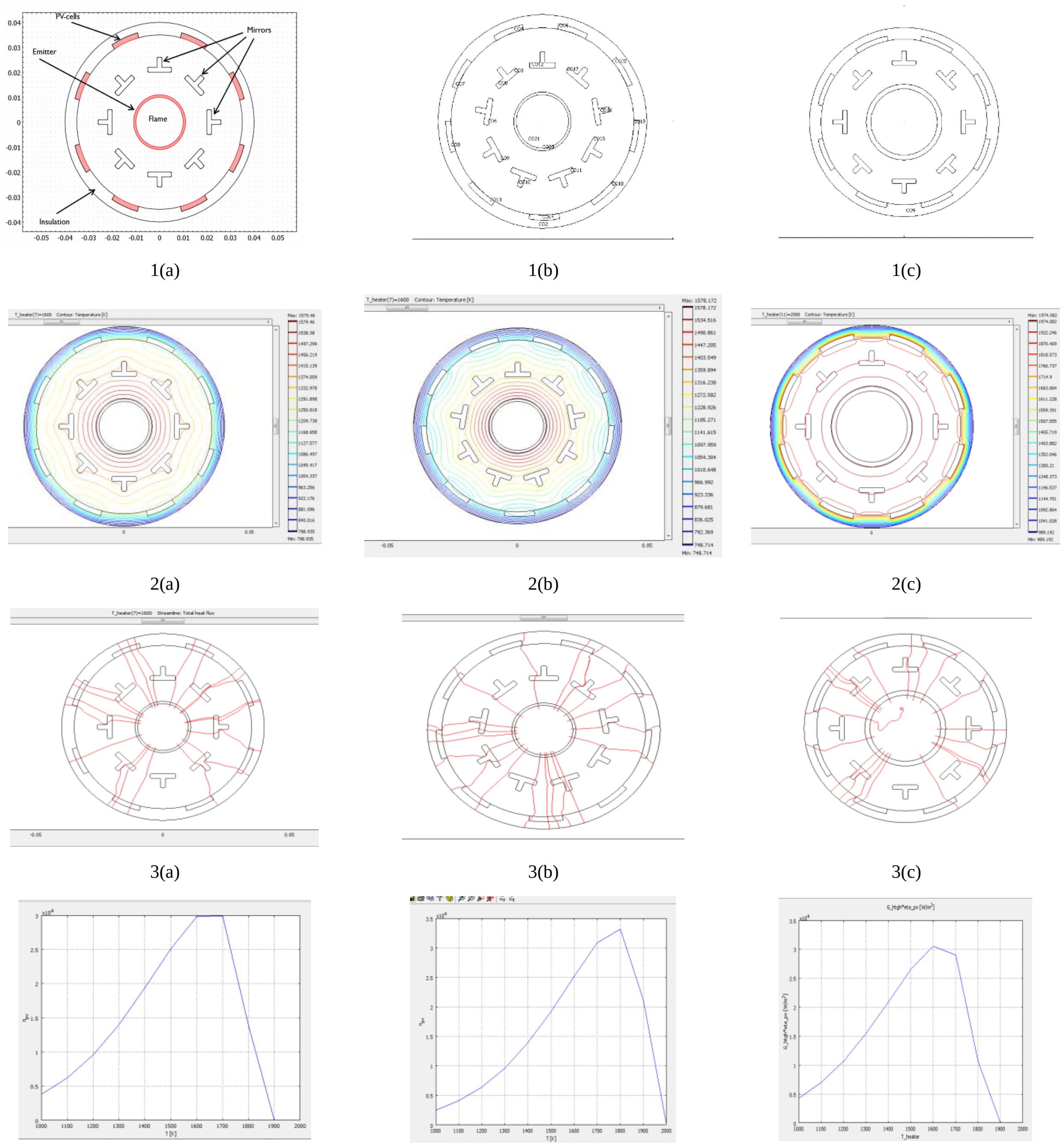


Figure 1-4: The thermal properties of the TPV cell based on its geometry modeling.

B. The Second Group

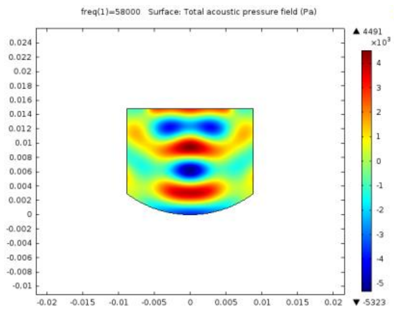
The second group investigated the addition of extra levitation pocket by increasing transmitter reflector intervals by comparing the work done by previous researcher [8]. Levitation has always been an interesting topic within scientific community, partly due to human fascination of things that can float in the air but most of all is the application of such technology to the existing field of industry complex may allow us to produce product that was unable to be made before. Many ideas have spring forth throughout history to make levitation of an object feasible, and with it comes great leap in technological products. One such example is magnetic levitation which generate lifting force from the repulsion force of two same pole magnet, be it those magnets are permanent or electrical in nature. Bullet trains that can travel at a velocity as fast as 431 km/h is the results of this application of magnetic levitation which allows it to escape from the frictional force generated by surface in contacts with the ground.

Another one such idea is the levitation of an object using acoustic wave, also known as acoustic levitation. What's so fascinating about acoustic levitation is that it doesn't just levitate the object that sits inside its levitation pocket but are also able to manipulate the object's position and spin without a second system interfering in the whole process. This container less processing techniques has made its way into some industry that deals in the acute manipulation of material. One such industry is the medical industry, with acoustic levitation medical solution could be prepared without using any physical container which increases the accuracy of the composition of the final product.

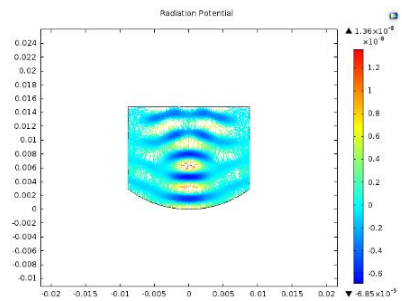
In [8] experiment, they used a single-axis acoustic levitator consists of an emitter and a reflector. The interval between the emitter and the reflector, H was adjusted at 1.5λ to excite the n = 3 resonant mode of acoustic field, where n is the mode of standing wave. In this mode, there were three possible levitation positons along the symmetrical axis among which the middle was chosen to levitate the living animals.

This group said that the design of the levitator model in COMSOL resembled that of the levitator used by [8]. By keeping the frequency of the acoustic waves constant, the emitter reflector intervals was adjusted to increase the number of available pocket. Figures 5 and 6 showed a 2D acoustic levitator model mimicking the work done by the mentioned researchers with $H = (5/2)\lambda$ and $H = 3\lambda$ respectively. Figures 5(a) and 6(a) are 2D plots of acoustic pressure, 5(b) and 6(b) are 2D plots of radiation potential and 5(c) and 6(c) are line graphs of vertical acceleration against y-axis. The adjustment of H produced n = 5 resonant mode in Figure 5, while n = 6 resonant mode in Figure 6. From Figure 5(b) and 6(b), the group deduced that for radiation potential profiles of levitator system, the particles preferred the lowest potential possible since all the region surrounding were higher in radiation potential and they were trapped inside the potential well generate by the acoustic levitator system.

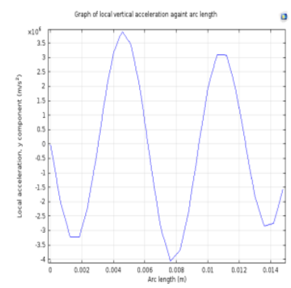
From Figures 5(c) and 6(c), the group explained that despite the particles being trapped inside the potential well, if the placement of the particles was not optimal which was right at the center of the potential well, oscillation occurred which resembled that of a harmonic oscillation.



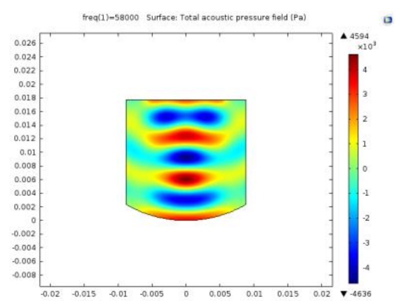
5(a)



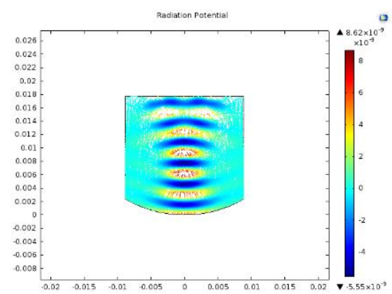
5(b)



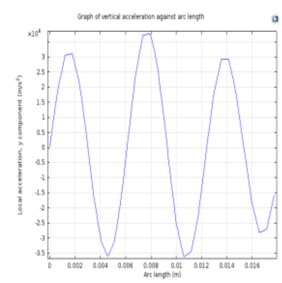
5(c)



6(a)



6(b)



6(c)

Figure 5-6: Acoustic Levitator model with adjusted *H.*

VI. CONCLUSION

Students-centered activity like POGIL could help students improved their essential skills in research without they even realized it. Before we attempted this exercises, we often wondered whether these third year students can actually performed the activity without the instructor teaching them how to handle the software. However, we must prepared that there will be a lot of questions coming from the students, and this was what inquiry learning is all about. With advance gadgets such as android phone, people are not communicating anymore.

From the outcome activities of the two groups, we can conclude that they learned a lot from their team effort. They need to do the literature reviews, to discuss about the objectives of their modifications, to do the simulation and to present their ideas. However, the simulation software has the disadvantage. The software solve the equations involve in the modelling for the students, as a result, they did not even care in where the equation came from or how they solved it. This we gathered when we asked questions regarding the theoretical part. As a conclusion, students were eager and now ready for the next step of doing their actual research or project on electronics devices and photonics for their final year thesis.

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