Design-based Learning in the Engineering Science Programme: Major Design Project on Solar-powered Buggy

Associate Professor Palani BALAYA
Department of Mechanical Engineering
Engineering Science Programme

Introduction

In the current era, it is mandatory to raise student awareness about renewable energy resources to mitigate the effects of climate change. In order to achieve significant progress in the adaptation of clean energy resources, it is important that innovative research and development, government policy and market penetration of renewable energy technology merge. However, to promote the development of innovative ideas, students must first be taught the relevant basics and given hands-on experience. My teaching highlights the importance of building students’ knowledge and awareness of renewable energies in order to motivate them to adopt such renewable energy options.

For this purpose, I have formulated two modules under the Engineering Science Programme (ESP), which are related to renewable energy sources. They are ESP3401 “Photovoltaic Devices & Systems” and ESP3901 “Major Design Project”, covering topics such as solar energy conversion and energy storage using battery/supercapacitors. Both modules employ the principles of design-based learning (DBL), which “uses the design of objects, forms or spaces as projects to facilitate learning” (Jolley, 2013; Wijnen, 2000). My intention is to imbue students with the fundamental knowledge relevant to solar energy conversion through ESP3401 and give them the opportunity for hands-on practice through the module ESP3902 “Major Design Project”. In this article, I talk about the following:

• how the principles of DBL have informed the way in which these modules have been implemented
• how students from the energy systems specialisation of ESP have benefited from doing the major design project involving solar energy conversion, and
• provide evidence and preliminary findings on how they applied and implemented such knowledge and skills during their Final Year Projects (FYP), which has resulted in some of them publishing high quality articles in international journals, filing patents of their innovative ideas or even going on to win several awards.

Ultimately, the activities in these projects should, according to Gómez Puente et al. (2011) “prepare students for good design practices” (p. 145).

Recommended Citation

Applying Principles of Design-based Learning in ESP Modules

According to Gómez Puente et al. (2011), DBL is used extensively in higher engineering education as it can “motivate students as creative professionals to collectively apply knowledge and skills in newly designed systems, thereby highlighting six features...professionalism, activation, cooperation, authenticity, creativity, integration and multidisciplines” (p. 138). In a recent review study, Gómez Puente et al. (2013) identified four dimensions in which the features of DBL can be organised. They are encapsulated in the following questions (p. 722):

- What project features are characteristic of DBL projects?
- What are the methods teachers use to support students in DBL?
- What assessment methods stimulate learning in DBL?
- What are the salient features of the social context of DBL?

In the next few sections, I will attempt to highlight aspects of both modules which display characteristics of DBL.

Methodology

According to Gómez Puente et al. (2013), DBL projects consist of “open-ended, hands-on, authentic and multidisciplinary design tasks resembling the community of engineering professionals” (p. 718). For ESP3401, I had structured the syllabus in such a manner that they learn the following:

- the basics of semiconductor materials used in solar cell devices,
- the different types of devices, and
- the system approach.

In parallel, the module ESP3902 “Major Design Project” provides students with hands-on experience and the opportunity to apply that knowledge. Throughout the course of participating in their respective design projects, students also developed their knowledge of technologies related to energy storage and the capability to integrate both solar modules and storage devices on several platforms, including an eco-friendly golf buggy, a transporter or an unmanned land rover.

At the ESP, we introduce design projects from as early as the students’ second year into the programme, so that they would be able to apply the scientific principles they learnt in the lectures during their foundation years. In the design projects, students work in groups to formulate, analyse and design experiments, as well as recommend solutions for an industry-relevant problem or issue. Such group work gives them the opportunity to develop interpersonal skills and be team players. The design projects emphasise hands-on experimentation, the chance to display creativity, and are multidisciplinary in nature, key elements of design-based learning. They also involve learning important techniques which students need to acquire to carry out scientific research, such as how to conduct an information search, operate electronic instrumentation equipment, acquire real-time experimental data, analyse errors, apply statistical methods and write computer programmes.

In order to train students on energy systems for their design projects, I took the initiative of setting up the ESP Design Studio¹, which spans 100 square metres and is located at E3-05-19 in the Faculty of Engineering. In this laboratory, students have a physical space in which they can fabricate simple laboratory-type devices such as dye-sensitised solar cells, lithium batteries, supercapacitors and more. They are also trained in the studio to test and analyse collected data on various types of solar cells such as monocrystalline silicon (Si), polycrystalline Si,
amorphous Si or dye-sensitised solar cells and organic solar cells as well as storage devices such as batteries and capacitors. Such systematic training can help students develop concepts for systems with different design considerations, such as high energy or high power or both, for different types of applications.

Thus, as the ESP students embarked on the design project during their third year, they explored and developed a scaled-down version of the applications to provide proof of concept. The five to six teams comprising ESP and mechanical engineering (ME) students worked on their respective design projects. Each group comprised students from diverse engineering specialisations. Along with students from the energy systems specialisation, students belonging to the computational engineering science specialisation and a few ME students also joined forces to complement each others’ knowledge to develop a specific platform (i.e., golf buggy, transporter or unmanned land rover) at the system level. The co-operative and collaborative dynamic within the groups is a key feature of design-based learning (Wijnen, 2000). Students specialising in energy systems were expected to use a suitable power generator as well as an energy storage system capable of operating the miniaturised platform (e.g. golf buggy), while the computational engineering science students will analyse and design the miniaturised and lightweight (about 3 kg) golf buggy to accommodate the power system. A few third year ME students also became involved this project to provide their expertise in analysis and the fabrication process.

So far, we have conducted this major design project for five academic years starting from AY2008/09. All members of the different groups worked together for about 13 weeks to demonstrate the operation of a specific platform (e.g. golf buggy) in AY2008/09 and AY2009/10.

Each team was given five hundred dollars to purchase the materials and tools required for this design project. Phoenix Solar and Renewable Energy Corporation at Singapore sponsored S$4000 for this design project on alternate years. Continuous funding support from industries for this design project for the last four years since AY2008/09 is an indication of the relevance of this project to the industry.

The primary tasks for this design project to develop a solar-powered golf buggy (AY 2008/09; AY2009/10) include:

- Identifying the problem or need for eco-golf buggies
- Assessing client requirements (e.g. visiting the golf course) to define the problem
- Searching for information/reviewing the state-of-the-art
- Identifying functional requirements and constraints
- Evaluating ideas against specifications for golf buggies
- Identifying components for the design of solar power as well as storage systems
- Simulating a simple design for the scaled-down version
- Fabrication of the golf buggy based on the models
- Developing prototype solar cells and storage devices
- Developing a full-fledged solar power system for the mini golf buggy
- Preparing a report and presenting their innovative designs.

The evaluation criteria are listed below:

<table>
<thead>
<tr>
<th>Tasks evaluated</th>
<th>Marks allocated (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interim presentation and report</td>
<td>15</td>
</tr>
<tr>
<td>Work attitude</td>
<td>15</td>
</tr>
<tr>
<td>Design achievement</td>
<td>30</td>
</tr>
<tr>
<td>Final report</td>
<td>20</td>
</tr>
<tr>
<td>Presentation</td>
<td>20</td>
</tr>
<tr>
<td>Total marks awarded</td>
<td>100</td>
</tr>
</tbody>
</table>
Results and Discussion

In the first few weeks of the semester, we conducted several design briefings and guest lectures for students. The topics were all geared towards supporting students in design-based learning, including project management and the finite element method relevant for the computational design, engineering drawings and the status of silicon solar technology. Every week we also scheduled three-hour project sessions in the ESP Design Studio for students to interact with lecturers and get guidance on their designs. Such sessions were helpful in providing “process-oriented instruction [that] is central to design-based learning environments” (Gómez Puente et al., 2013, p. 721).

In Week 6, we evaluated the progress made by the project teams based on their interim reports and respective presentations, providing “formative feedback on design tasks...[and] on processes to undertake these design activities” (Gómez Puente et al., 2013, p. 728). This was quite useful as the teams could get an update of the progress they have made and the lecturers could also provide relevant suggestions to streamline the goals of each team. By Week 11, students had fabricated a specific platform (e.g. a golf buggy), optimised its power requirements using commercial silicon solar panels and lithium-ion batteries as well as testing the vehicles for several minutes of operation. The final report was submitted in Week 12, and we conducted the final examination/presentation in Week 13. Each group had to give a 30-minute presentation, followed by a 15-minute Q&A session.

In addition, students also demonstrated the operation of their solar-powered mini golf buggies for about eight minutes during a competition held among the teams (see Figures 1 and 2). The golf buggies were subjected to incline tests at a maximum slope of 1:3 and terrain/environmental tests similar to what these buggies will experience on a golf course. All five buggies performed well in the competition where they were judged by a jury committee according to the number of golf circuit laps, maneuverability, stability, aesthetics and innovative features.

continued on the next page...
Sharing Our Experience and Challenges Encountered

As a lecturer, I had an excellent teaching experience during the implementation of this design project. When we introduced the design project in AY2008/09, this was carried out over two semesters and the students were offered eight modular credits (MC). However, mindful that some students may be away on their exchange programmes, we decided from AY2009/10 to offer this design project for one semester and converted this to a four-MC design project with reduced expectations on the deliverables.

In a conversation with Yi Han, one of the team leaders from the AY2008/09 batch, he shared that he found the design project intellectually challenging and a great learning experience. He added that he learnt the importance of teamwork, leadership and overcoming the odds.

In contrast, the teams from the AY2009/10 cohort found the major design project to be quite challenging with a high level of competition, keeping in view that this project only carried four MCs and had to be completed within one semester. Unfortunately, the teachers had limited interaction with students during the laboratory hours as the students were making progress outside the ESP Design Studio in order to avoid exposing their design concepts to other teams. During the final competition, we also noticed that one of the teams that had lost the award was quite upset.

Refining the Evaluation Criteria

In order to avoid such bad experiences, in AY2010/11, AY2011/12 and AY2012/13, we made several changes to the design criteria and informed students well in advance of our expectations to avoid any communication gaps.

For the teams from the AY2012/13 cohort, we used the following evaluation criteria for the design project to develop a solar-powered unmanned land rover (ULR):

<table>
<thead>
<tr>
<th>Tasks evaluated</th>
<th>Marks allocated (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interim presentation and report</td>
<td>15</td>
</tr>
<tr>
<td>Quiz (conducted at the beginning of the 8th week, just after Recess Week)</td>
<td>10</td>
</tr>
<tr>
<td>Performance of prototype ULR:</td>
<td></td>
</tr>
<tr>
<td>a) Operational efficiency (10%)</td>
<td>30</td>
</tr>
<tr>
<td>b) Energy efficiency (10%)</td>
<td></td>
</tr>
<tr>
<td>c) Charging efficiency (10%)</td>
<td></td>
</tr>
<tr>
<td>ULR design, innovation and functionality</td>
<td>15</td>
</tr>
<tr>
<td>Final report</td>
<td>20</td>
</tr>
<tr>
<td>Oral presentation</td>
<td>10</td>
</tr>
<tr>
<td>Total marks awarded</td>
<td>100</td>
</tr>
</tbody>
</table>

The quiz, conducted just after the Recess Week, provided an opportunity to evaluate students’ knowledge on fundamental concepts taught.

As listed above, the criterion on performance of the prototype ULR carries 30% of the total marks. To be more precise in our evaluation, we introduced innovative approaches to judge the performance of the ULR. In AY2012/13, we provided the following details to evaluate the vehicle’s performance:

- **Operational efficiency** of the ULR was evaluated based on the time required for the vehicle to complete fifteen rounds. The most operationally-efficient ULR is the one that completes the fifteen rounds within the shortest time.
• **Energy efficiency** of the ULR was evaluated based on the energy needed to complete the fifteen rounds. The students removed the batteries from the ULRs after the demonstration, and drained the remaining power in the battery by connecting it to an electrical load. The most energy-efficient ULR is the one that was able to power the electrical load for the longest time.

• **Charging efficiency** of the ULR was evaluated based on how much energy can be collected by the solar cells. This was not estimated on-site. As such, the students submitted their ULRs to the Design Studio after the demonstration. We drained off the power of the battery and then charged the ULR for five hours using solar energy. After completing the charge, the battery capacity was evaluated using a battery tester. The most charge-efficient ULR was the one with solar cells that was capable of charging the battery back to the highest level of power.

The introduction of such evaluation criteria has helped students’ learning in the following ways:

• Students gained knowledge on basic concepts relevant to their course due to the quiz we conducted.

• Improvements in communication, which meant that students received clear instructions about the evaluation procedures as well as being aware of our expectations of their design. This helped students to prepare their designs accordingly without any extra effort.

• Provided a platform that put emphasis on design aspects rather than adopting research methodology.

• An opportunity for students to display the characteristics of design-based learning while doing the design projects, such as the ability to integrate and apply the knowledge they acquired in ESP3401 creatively.

### Outcome of the Major Design Project and Student Feedback

This third year Major Design Project, with a focus on solar power for energy harvesting and using lithium battery/supercapacitors for energy storage, offered ESP students a great opportunity to become familiar with renewable energy sources and develop problem-solving capabilities which would be sought after by industries which develop electric vehicles, solar houses, microgrids and more. In addition, the experience of working in multidisciplinary groups and having to complete design tasks that were embedded in “open-ended, hands-on experiential and authentic learning environments” (Gómez Puente *et al.*, 2013, p. 727) meant students had the opportunity to develop leadership qualities and cultivate positive group dynamics. They also garnered several awards² based on their innovative ideas. Thus, it is evident that the Major Design Project offered in the Engineering Science Programme helped students to develop and apply skills which reflect the six elements of design-based learning, namely professionalism, activation, cooperation, authenticity, creativity, integration and multidisciplines.

Such design-based learning has generated great interest among students to undertake several final year projects (FYP) involving renewable energy sources and energy storage options. Students are thus well informed about novel concepts such as microgrid sources, solar energy, wind energy and so on. Since these renewable sources are intermittent, students also had to learn about large-scale storage systems. Lithium-ion and sodium-ion batteries are currently considered possible economical options for such stationary storage applications. ESP students are then offered FYP projects on the above topics related to energy harvesting and storage. Due to their exposure to such technologies when they participated in the major design projects, these students performed

*continued on the next page*
extremely well for their FYPs. So far, three FYP students have filed three US provisional patents as well as published articles in international journals based on their invention of innovative electrode materials for lithium-ion and sodium-ion battery systems.

Students also provided positive feedback on how the Major Design Project enhanced their learning and its relevance to their future careers. For example, Ivan Yeo (currently working as a research engineer at DSO Laboratories) who did his Major Design Project and also his FYP under my supervision, wrote an e-mail to me saying, “My work on batteries for the solar golf buggy in Year 3 sparked my interest in studying batteries and battery systems. Thus, I chose a FYP which involved research on batteries. This FYP not only increased my knowledge of batteries, but also trained me to learn and develop independently. I gained an insight into the field of research and learnt several important research methodologies which could also be applied to professional work in other fields”. It is clear from Ivan’s email that the lessons he learnt and skills he picked up from participating in these projects have made a positive and long-lasting impact on his learning.

Endnotes

1. The energy systems laboratory (located at E3-05-19 in the Faculty of Engineering) houses facilities such as a fume hood, furnaces, ball mill facilities, a combined thermo-gravimetric and differential scanning calorimetry, a solar simulator for I-V measurement, an incident photon to current conversion efficiency (IPCE) measuring equipment for solar cells, a doctor blade for coating electrodes, a roller press, a glove box, a battery tester and computers.

2. The winning team from the first batch in AY2008/09, comprising Chow Siew Wei, Kevin Pye, Wang Pai, Dilip Joy Thekkoodan and Foo Ce Yang, went on to win the NUS Outstanding Undergraduate Researcher Prize. The team also received a High Achievement Award during the 23rd Faculty Innovation and Research Competition in 2009.

3. Two students, Huang Zhixiang and Malcolm Ong Jin Yuan, jointly won the Merit Award during the 27th Faculty Innovation & Research Competition in 2013 based on their FYPs on the sodium ion battery.
Acknowledgement

The author is grateful to Solar Phoenix Pte. Ltd and Renewable Energy Sources, Singapore for their sponsorship. The author also thanks Professor C.M. Wang, Dr. Erik Birgersson and Dr. Adrian Koh Soo Jin for the constructive and useful points they provided during discussions about developing this design project.

References


About the Author

Assoc Prof Palani Balaya (pictured, left) teaches at the Department of Mechanical Engineering and also serves as an Associate Faculty in the Engineering Science Programme. His current research interests include energy conversion and storage.