An Engineering Workspace for Integrating Sustainability Applied Research into Learning

Chee Siaw Soon, Eunice Goh, Hannah Gardner, Wang Yadong, Leonard Loh, Choo Keng Wah

Diploma in Nanotechnology and Materials Science, School of Engineering, Nanyang Polytechnic Singapore.

ABSTRACT

With the advancements in the fields of nanotechnology and material sciences, engineering students from the Diploma in Nanotechnology and Materials Science (DNMS) in the School of Engineering, Nanyang Polytechnic, are required to solve complex, interdisciplinary and multidisciplinary problems. A new engineering workspace, **N**anotechnology and **A**dvanced Materials **T**eaching facility for **Ur**ban **E**nvironments (NATURE) was set up to provide inter- and multidisciplinary learning opportunities for students from different disciplines: engineering, materials, information technology, health sciences, chemical and life sciences and agronomy. This paper describes how NATURE is used as a platform to integrate sustainable technology applied research into the curriculum of the DNMS. The aim is to nurture students' inquiring mind and to develop their research skills as well as problem identification and problem solving skills. This paper also discusses the effectiveness of this platform to allow lecturers, students and industry partners to work collaboratively on multidimensional interdisciplinary applied research projects in NATURE, thus making learning more experiential and engaging for students. Finally, this paper highlights the challenges faced and provides recommendations for future adoption of this approach in general engineering education.

KEYWORDS

Collaboration between Academia and Industry, Engineering Workspaces, Faculty Development, Learning Environments, Standards: 6, 7, 8.

Notes: *1) In the context of Nanyang Polytechnic, the term 'course' refers to a 'program' while the term 'module' refers to a 'course'. For example, Diploma in Nanotechnology and Materials Science is a course; Materials Science is a module.*

2) Interdisciplinary studies refers to the integration of knowledge from different disciplines, for example combining the knowledge from the fields of engineering with chemical and life sciences.

3) Multidisciplinary studies refers to the study of different subjects within the same discipline, for example learning of chemistry and materials science are essential for students in DNMS. Multidimensional interdisciplinary learning refers to learning in various forms such as lecture, projects, applied research programmes outside of a structured classroom and industrial collaboration.

MOTIVATION

The Diploma in Nanotechnology and Materials Science (DNMS) in the School of Engineering, Nanyang Polytechnic (NYP) offers interdisciplinary studies covering science and engineering know-how on materials that are at the nanometre scale. The students acquire knowledge and skills in these disciplines and are able to apply them in developing new materials and applications. To imbue these knowledge and skills to our students in supporting Singapore's manpower needs and economic growth, we reviewed our curriculum in 2014 by conducting an industry landscape scan and gathering feedback from the government agencies.

Through this process, we identified emerging fields that are important to the industry in Singapore, including energy harvesting and storage, water treatment, thin film and coatings as well as environmental sustainability. In addition, one of the recent key initiatives by the Singapore government was the Sustainable Singapore Blueprint (The Sustainable Singapore Blueprint 2015). Singapore has made significant inroads into the sustainable technology market in a short span of time. The government has committed over $4 billion for a 5 year plan starting from 2016 under the RIE2020 plan to support technological capabilities such as aerospace, electronics, medical technology manufacturing and urban solutions & sustainability, with advanced materials identified as one of the key enablers that cut across these areas. SPRING (an enterprise development agency for small and medium size companies) identified several important enablers including advanced materials and nanotechnology which they were targeting to take Singapore's manufacturing industry to the next level.

In aligning with the industry and to support the government's initiative to build a Sustainable Singapore, a new specialisation on Materials for Sustainable Technology was introduced as a third year specialisation in the Diploma in Nanotechnology and Materials Science. The set-up of the workspace was an essential component to assist with the training of our students for this specialisation.

The motivation in setting up the workspace in sustainable technology were guided by several needs:

1) *Real-World Contextualisation and Active Learning*: NYP's curriculum is driven by an outcome based approach which is to produce industry-ready graduates. The facility was envisioned to be a space not only for training of students in their course work and in their projects, but to also allow students to have an experiential environment which simulates the real-life needs of working with people from the industry.
2) *Integrated Learning Experience*: One of the issues often faced by students is to link the fundamentals taught in school with actual application. A laboratory can provide useful hands-on work for students, but has limitations and may be focused in scope. By having a workspace where students are encouraged to participate from the first year of their studies in portions of the projects in the workspace, will allow them to appreciate the fundamentals taught better.
3) *Interdisciplinary and Multidimensional Learning*: Sustainable technology is a field that cuts across various disciplines and a project often requires teams from the various

fields to work together. The concept was to design a workspace which acts as a focal point which will allow interdisciplinary and multidisciplinary collaboration among students, staff as well as industry.

The following sections describe the approach we took to innovate a learning environment based on CDIO standards 6 (Engineering Workspaces), 7 (Integrated Learning Experiences) and 8 (Active Learning).

NYP OUTCOME BASED LEARNING APPROACH

Several set principles are used as a guide in developing the curriculum for the Diploma in Nanotechnology and Materials Science (DNMS). The overall aim at NYP is to provide students with an education that is driven by present and anticipated industry needs, so as to produce industry-ready graduates who are professionally proficient, competent in 21st century skills, innovative & enterprising and socially responsible. These attributes will assist them in making greater valued contributions to the Singapore economy and society upon graduation.

The School of Engineering at NYP developed curriculums based on the CDIO principles and guidelines (Crawley, Malmqvist, Östlund, & Brodeur, 2007) (Choo, Tan, Chong, Kwek, 2015). An outcome-based learning strategy to design an applied learning curriculum (Figure 1) was used where the instructional and assessment strategies are designed to align with the intended outcome. The instructional outcome in turn should meet the module outcome which will also be needed to meet the intended course outcome.

To further strengthen the learning process for the students, the course curriculum design for the DNMS also uses an integrated applied learning curriculum design approach. Students are exposed to integrated learning where the modules are interlinked and connections made between subjects learnt within the semester and through-out the 3 years' of study using a structured categorisation of modules. Students' fundamentals are grounded in the first year through the basic mathematics and sciences. In their second year, materials are introduced to students, linking back to what was studied in the mathematics and sciences, such as Chemistry and Physics. Mini-projects are devised using knowledge gained in the previous semesters where students can conceptualise ideas based on their knowledge learnt. The application of materials are introduced in various fields through different specialisations such as Materials for Sustainable Technology (MST) or Advanced Electronic Materials and Semiconductor Technology in their final year of studies.

The introduction of a specialisation in Materials for Sustainable Technology was recently included due to industry needs and the strong shift towards sustainability and use of green technology. In the emerging field of sustainable technology, as with many real-life applications, it is often multidisciplinary and multidimensional. To assist with providing the intended outcome of producing industry-ready graduates in the field of sustainable technology with the graduate attributes mentioned above, the set-up of a workspace was important. The workspace will provide opportunities for the students in multidisciplinary learning which can enable them to possess multidisciplinary perspectives and be professionally proficient to work with different people with different backgrounds to solve real life sustainable technology problems. It will also train them on essential skills in critical and inventive thinking which will enable them to generate innovative solutions through the awareness of global, industrial and environmental issues as

well as develop an understanding of compassion to the community which provide relevance to sustainable technology.

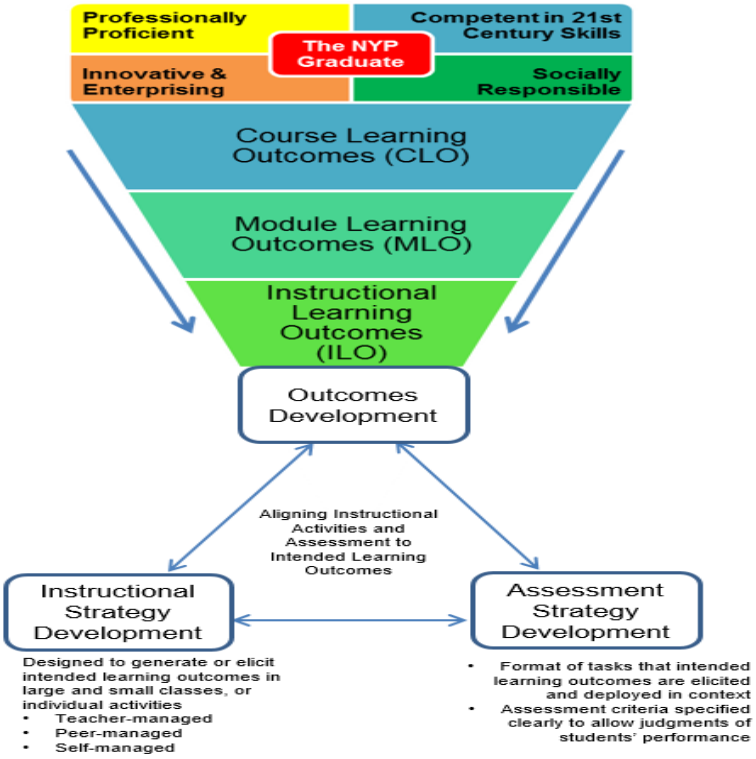

Figure 1: NYP adopted an outcome-based approach to design an applied learning curriculum.

METHODOLOGY

Our integrated curriculum provides a basis of guiding our students through the many modules within their curriculum, and providing a link between modules. However, students in the first and second years tend to have a harder time putting into context the theories learnt using the traditional approaches to teaching and learning pedagogy. Traditional approaches to teaching and learning at the tertiary levels come in the form of lectures, tutorials and laboratories. The learning format in the lectures and tutorials help to provide the necessary fundamentals and theoretical knowledge to students, but may not provide the necessary avenues for them to link to real-life scenarios and applications. This is particularly important from an engineering context as graduates from engineering programmes need to apply their knowledge to applications and products.

A Novel Engineering Workspace: NATURE

To achieve the intended learning outcomes in the area of Materials for Sustainable Technology, an experiential learning space, termed as **N**anotechnology and **A**dvanced Materials **T**eaching facility for **Ur**ban **E**nvironment (or NATURE) was set-up. NATURE is a sustainable facility which incorporates urban farming with alternative, renewable and environment technologies.

The objective was to create an integrated research and teaching & learning environment for module delivery and interdisciplinary collaborative research in the field of advanced materials for sustainable living, renewal energy and environment management. The knowledge based needed within this facility covered a wide range from materials, electrical and mechanical engineering, information technology, agronomy, chemistry and food science. There has been earlier reports of greenhouses set up for educational purposes in the US for high school students (Rothenberger & Steward, 1995) and tertiary education (Franklin, 2008), and these were specific for the training on agricultural and horticultural technologies.

Several pedagogical initiatives were implemented in this living laboratory facility whilst aligning to CDIO standards (CDIO Standard 2.1). Figure 2 highlights the key initiatives and projected outcomes for our engineering workspace pedagogy. This living facility served as an Engineering Workspace (standard 6) which allowed students to have more hands-on experience on real life technologies in the facility. This engineering workspace also provided integrated learning (standard 7) experiences as diverse technologies are housed in the engineering workspace. The workspace encouraged interdisciplinary collaboration through collaborative project work within and across different schools and multidimensional collaboration between individuals, academic departments, community and industry. The incorporation of the students' involvement from the first year (where they are taught the fundamentals in sciences, mathematics and materials), helped students make connections with the knowledge learnt in the curriculum. The real life technologies in the facility which promotes industry collaboration and also enhanced active learning (standard 8) as students were engaged directly in critical thinking in solving real life problems. The availability of this living laboratory facility provides a user-centric, open-innovation ecosystem which influences the experiential learning significantly.

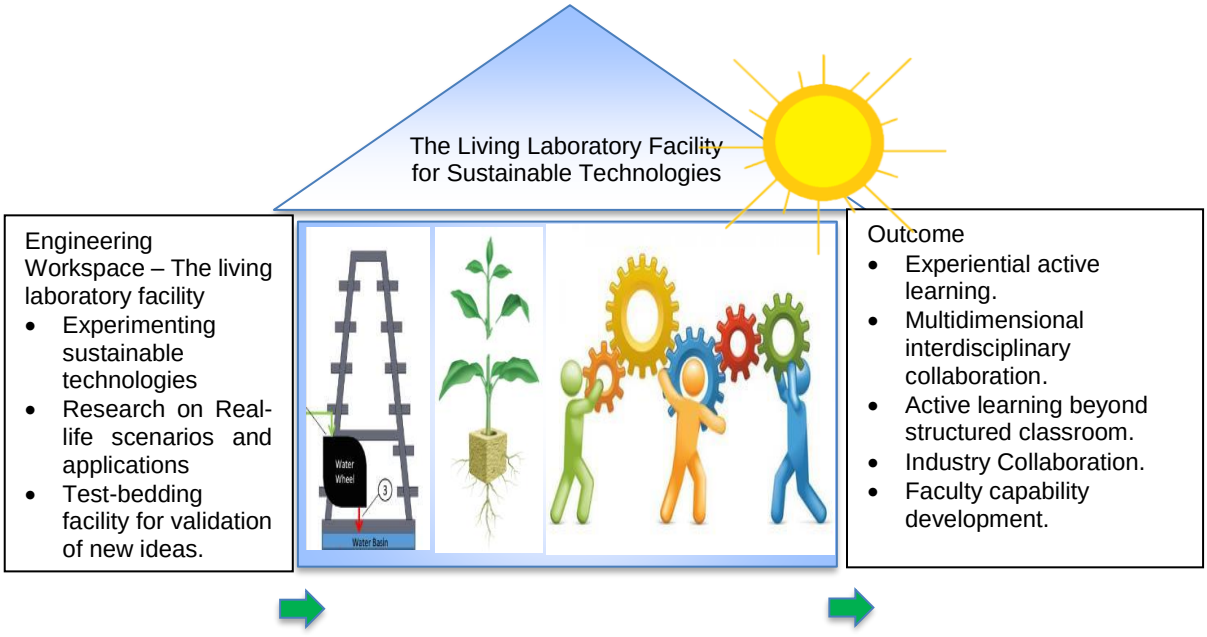

Figure 2: Key initiatives and projected outcomes for the sustainable technology engineering workspace.

A Facility and Platform for Interdisciplinary Project

NATURE is a 9 m by 6 m greenhouse with a height of 4 m, built with sufficient space to facilitate teaching a class of about 25 students, which is the equivalent size of one tutorial or laboratory group (see Figure 3). The main feature is a novel space-saving automated vertical farming system suitable for urban environments which allows a controlled growing environment within an enclosure. Two 3 m high rotating vertical crop stack systems with 12 stacks with a foot-print of 3.75 m by 1.5 m each, allow increased land use and a recycled water tank. The recycled water is used to provide automatic crop irrigation and a water wheel is used to power the rotating crop stack. NATURE runs on low carbon and low power, where the only power required is for the pump to circulate the water in the baths. Rotation of the towers are by gravity administered by the circulation of the water from the water wheel. This concept also requires low water supply, significantly less than a farm of the same area (Sky Greens, Singapore). NATURE also houses smaller test systems for aquaponics, aeroponics, hydroponics and traditional soil beds as well as solar and battery energy harvesting applications.

Figure 3: The new engineering works learning space, termed as **N**anotechnology and **A**dvanced Materials **T**eaching facility for **Ur**ban **E**nvironment (or NATURE).

CURRICULUM DESIGN AND PEDAGOGICAL APPROACH

A Contextualised Curriculum

According to CDIO Standard 1, the appropriate context for engineering education must be provided as graduates from engineering programmes need to apply their knowledge to product, process, and system lifecycle development and deployment.

Several pedagogical initiatives that align to this principle have been implemented using NATURE as a training platform which is meant to provide a student-centric, open-innovation ecosystem, contextualised environment that enhances the learning experience of the students from the first year of their studies.

These include:

- Introduction of active learning within the space
- Experiential learning through hands-on work in this living laboratory facility
- Interdisciplinary collaborative projects among students

An Outcome-based Approach

As discussed earlier, NYP adopted an outcome-based approach to designing an applied learning curriculum. Figure 4 shows the module learning outcome for Sustainable Materials Technology. In the past before the existence of NATURE, students learn the concept and knowledge via lectures or tutorials. With the various sustainable technologies housed within NATURE, the engineering workspace enhanced students' learning experiences by showing the actual application of materials usage in energy and environmental applications. This helps to provide students' more hands-on experience and also promote active learning. Students are able to appreciate the knowledge learned from the lecture and apply into real-life application.

S/No	Module Learning Outcome	Mapping to Student Learning Outcomes				
		EGDF13				
1	Recognize the various types of ecological footprint	l, n				
2	Understand the environmental impacts of materials and chemical processing	l, n				
3	Able to evaluate and critically assess environmental life cycles of various materials.	b, l, n				
4	Understand the application of advanced material usage in energy and environmental applications.	b, l, n				
5	Understand the water treatment technology for industrial and municipal wastewater treatment using conventional and advanced oxidation technology	b, l, n				

Figure 4: Module learning outcome for Sustainable Materials Technology.

All students from DNMS will do their Full Time Semestral Project in their final year of study in NYP. NATURE serves as test bedding facility to enable students to validate the ideas of their project. An example of a final year student's material project is one related to agronomy where students work on increasing the potential yield in urban farming and at lower costs compared to today's commercial technologies available. The students also gain a better understanding of the problems faced in the real-life scenarios of a living lab. A more controlled environment together with the automated irrigation system provided by the greenhouse mean the results from the studies conducted by the students are more conclusive and convincing.

Figure 5: Student and staff involved in a project on wavelength shifting nano-coatings for increased plant growth and yield.

An Integrated Learning Experience

About 70 % of our students at the School of Engineering undergo 12 weeks of a full time semestral project and 12 weeks of internship in their final year of studies. The remaining 30 % undergo 24 weeks of internship. An average of 60 % of the DNMS students work on final year innovation projects related to NATURE since its construction in 2016. One of the key final year student project is in the area of materials development of nano-coatings which help shift the sunlight wavelengths that is essential for plant growth. The nano-coatings are placed onto trays on the vertical farming system and students study the effect of nano-coatings on plant growth. Plants are no longer grown in a laboratory environment but in an actual greenhouse. Another project is in the development of a self-sustainable zero energy facility for greenhouse with the utilization of a solar and energy storage system. This involves the optimization of solar PV and battery systems, battery charging/discharging algorithms, energy monitoring dashboard among others. High performance battery electrode materials are investigated and tested on the system. This incorporates knowledge in the fields of mechanical, electrical and materials engineering. Self-cleaning coatings using materials synthesis and coating knowledge are also developed to address the adhesion issues on the substrate. Agricultural sensors such as environment, nutrients and water levels are being developed, requiring the harnessing of knowledge in materials, agriculture, electronics and programming from various departments. These projects showcase and allow our students to be exposed to real-life issues in modules such as “Smart Materials”, “Sustainable Materials & Technology” and “Energy Harvesting and Storage” where lab sessions are conducted in NATURE. Group project meetings are conducted weekly where students and supervisors related to NATURE projects come together for discussion and for students to share with staff and fellow students’ different view-points. This allows sharing of ideas and information from the various groups.

To incorporate the use of the workspace for first and second year students, applied research programmes are introduced outside of structured classes to nurture critical thinking and brainstorming skills that are important for building the creativity and innovative thinking. These

skillsets are often difficult to impart through structured environments. This programme called the *Young Researcher Programme*, is our applied research programme designed to encourage integrated learning for the three-year curriculum focusing on sustainable technology. In this programme, the students assist with various sustainable technology projects from the first year. This helps to incorporate the practical knowledge needed and provides an added informal channel for the added dimension of blended learning to their course work. Students participating in the Young Researcher Programme are given mini-projects relevant to their level of knowledge in various areas of sustainable technology within NATURE. The students are also awarded Co-Curricular Activities points if they have met certain criteria set-up in the programme. This not only encourages students to participate in this event but also provides them with the incentive to put their best efforts into the programme. Two runs of this programme has seen overwhelming response from students wanting to participate in this programme and has also seen an increase in the number students choosing a NATURE project as their full time semestral project.

By creating fun and interactive activities within NATURE, students are indirectly infused with building a sustainable technology mind-set due to the nature of the projects and activities. This helps in bringing a deeper level of appreciation needed in social responsiveness. Based on feedback, students involved in the NATURE sustainable projects during their full time semestral projects as well as those participating in our Young Researcher Programme find the workspace a useful resource in honing their innovative mind-set as they find it more exciting working in an actual sustainable environment compared to the confines of a typical lab space.

An Active Learning Environment

Active learning aims to engage students directly in the learning pedagogy to promote higher order thinking and learning. NATURE has also been used as an active learning tool within the core modules in our curriculum.

Students from DNMS conduct their lab classes on solar technology in the Energy Harvesting and Storage module where they are able to do real-time measurements at NATURE. By conducting the class in NATURE, they get to appreciate how real-life constraints capacity requirement, shading profile, system efficiency and available space affect the solar measurements and parameters. NATURE has also been used as a facility for 50 students from various diplomas in their mini-projects as well as in integrated-multidisciplinary projects as inspiration for exploring innovative ideas for projects.

Students from the Diploma in Electrical Engineering with Eco-Design had used the facility to conduct real-time measurements of the power demand of the NATURE greenhouse as well as perform systems design for the solar and energy storage system as part of their full time semestral projects. The students were able to consider and incorporate the real-time constraints in their system design. This allows them to better appreciate the design methodologies taught in the classroom. They also have the opportunities to develop a test-bed system to verify their design specifications. Once the actual system has been installed, the

students will be able to monitor and analyse the energy supply and demand in the NATURE greenhouse while developing innovative energy management solutions to overcome problems related to supply and demand fluctuations.

Prior to the set-up of NATURE, these classes are conducted in indoor labs with simulated set-ups. By using NATURE as a workspace, the students were able to conduct solar cell design and characterisation in more realistic scenarios.

A Platform for Collaboration

Due to the multidisciplinary nature of the greenhouse facility, several technology related capability development projects were initiated. The major knowledge base required for NATURE in material studies and agronomy saw the sharing of knowledge between the School of Engineering for materials development and School of Chemical and Life Sciences in agronomy. Projects in the area of soil bed studies have been conducted using alternative materials like biodegradable polymers which will allow the infusion of fertilizers and natural pest control solutions such as for anti-dengue which will have a time release mechanism. Biodegradable plant pots are also being developed which allow the seedlings to be transferred to bigger pots without the need for transplanting. These studies need to be coupled with the understanding of plant physiology and factors affecting the growth of the plants. This engineering workspace also serves as a test-bedding facility for validation of new ideas.

The facility has also been used by Occupational Therapy students from the School of Health Sciences as part of their classes in Gardening Therapy, the Diploma in Chemical & Green Technology in training on Aquaponics and the use of the organic drying chamber. Vegetables and herbs are grown and supplied to the Diploma in Food Science and Nutrition for their classes and their feedback as well as tools in characterising food can help in improving the growth of the crops as well as provide knowledge from different disciplines to students who otherwise would not have access to.

Since its construction, NATURE has encouraged various industry partners to collaborate with the school and provide opportunities for students to solve the real life problems. Companies have approached NYP to place their systems at NATURE to conduct trial runs. Students are able interact with the industry and work on industry specification requirements and timelines. We often include our students in project discussions with companies, and also provide them with the specifications and requirements set by companies for their projects. This provided excellent means for the students to appreciate project management as well as the softer skills requirements that are needed when working with industry. This exposure has provided students with the opportunities to build on their 21st century skillsets and improve and understand the professional proficiency needed when interacting with industry.

RESULT AND FINDINGS

A survey was conducted to students who were involved in a range of activities that NATURE had to offer.

A survey was conducted for MST specialisation class of 22 DNMS students who had a laboratory session on solar cell characterisation in the Energy Harvesting and Storage module at NATURE, 19 students responded to the survey. The survey was done in a paper format and a few questions were asked in the survey (see appendix A). 95 % found that a realistic sustainable facility helped with their understanding of sustainable concepts taught in class. It was found that the students who did not gain as much knowledge were those students who were previously involved in projects in NATURE.

Another question asked was how students rate their knowledge and hands-on experience gained in comparison to prior knowledge before their activities in NATURE. The rating of the knowledge and hands-on experience gain was categorized into “Significant”, “Reasonable”, “Marginal” and “Not at all”. None of the students selected “Not at all”, 63% of students found they had gained “Reasonable” knowledge and hands-on experience, 16% and 21% of students found they have gained “Significant” and “Marginal” knowledge and hands-on experience respectively. In addition, 100 % of the students were in agreement (with rating of ”Excellent”, “Very Good”, “Good”, “Poor” and “Very Poor”) that the NATURE facility provided a good hands-on experience, with 53 % of students rated “Very Good” and 26% of students rated “Excellent” (Figure 6).

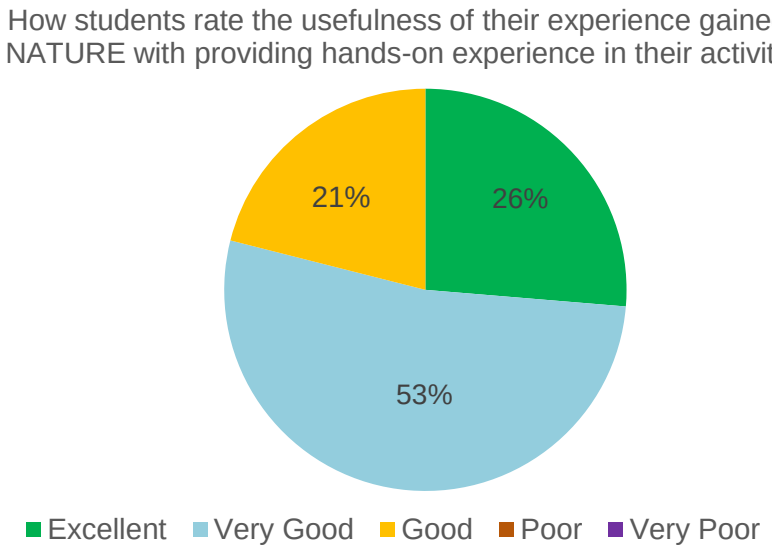

Figure 6: Student survey on usefulness of NATURE in providing hands-on experience as a laboratory class.

In addition, another survey was conducted with students who had used the living laboratory facility for their full time semestral projects. This survey was conducted as an online form using Google form. The questions asked were similar to the survey in Appendix A. 10 students were invited to participate and 6 students responded. The students were asked how their knowledge

gained in Sustainable Technology before and after their experience using NATURE. 100 % of the students were in agreement (with rating of “Excellent”, “Very Good”, “Good”, “Poor” and “Very Poor”) their knowledge gained after using NATURE for their full time semestral projects. 67 % of students rated their knowledge gained in sustainable technology related to agriculture “Very Good” and about 16.7% of students found their knowledge in this area improved to “Good” and “Excellent” respectively (Figure 7). All students agreed that the NATURE facility is a real life engineering platform to provide students a more hands-on learning experience.

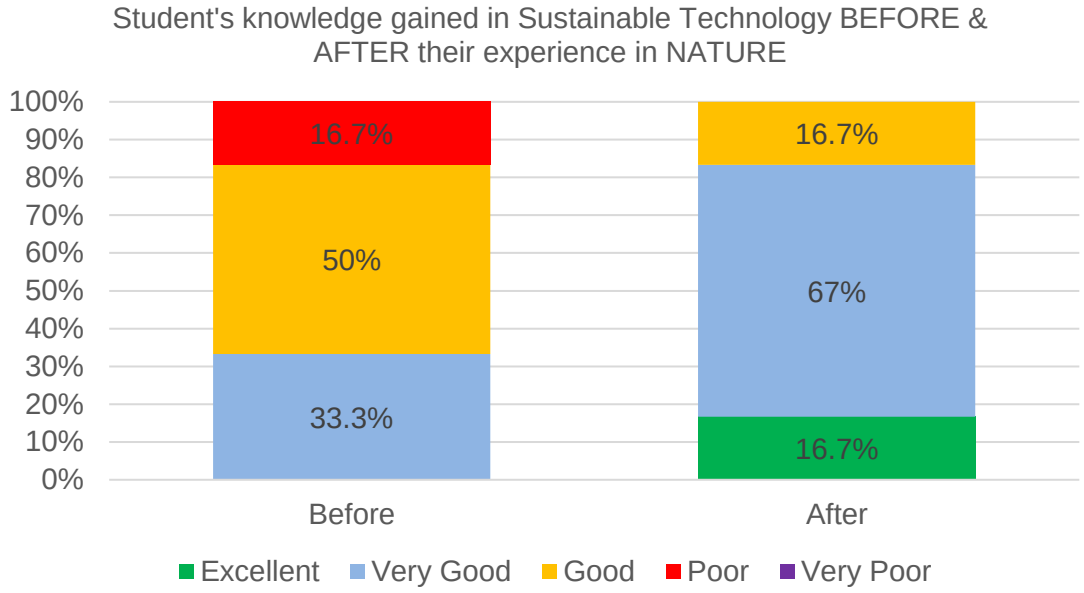

Figure 7: Student survey on knowledge gained in sustainable technology through their experience in NATURE.

In addition, all students agreed that they have gained more knowledge and hands-on experience after involving in NATURE. With rating of “Significant”, “Reasonable”, “Marginal” and “Not At All”, figure 8 has shown 50% of students found their knowledge and hands-on experience had significantly improved after using NATURE as an experimental workspace for their full time semestral project; 33% of students found their knowledge and experience had a reasonable gain and another 17% found marginal gain in his/her knowledge and experience. Different knowledge and hands-on experience gained by students could be due to the difference in the students’ project scopes. All of them however unanimously agreed that they will encourage their friends to join activities related to NATURE.

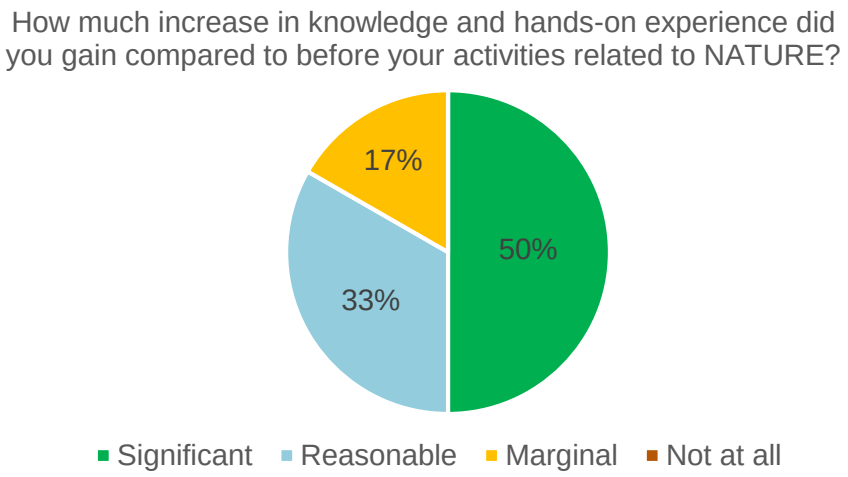

Figure 8: Student survey on their knowledge and hands-on experience gained due to activities related to NATURE.

In order to teach and mentor students in the multidisciplinary platform, lecturers are working with government agencies and industry partners to acquire knowledge and skills that are currently used by industry. This platform has also helped lecturers to bring relevant examples to the students and improve both their soft and technical skills outside of their respective disciplines. Lecturers share their experience with peers through Sharing Organisational Learning Interaction Dialogue (SOLID) sessions which foster the spirit of continuous improvement and professional development.

A survey was conducted to staff who were involved in NATURE. This survey was conducted as an online form using Google form, the questions asked were similar to the survey in Appendix A. Total of 7 staff were responded to this survey. Staff were asked how they rate their knowledge gained in sustainable technology after their experience in NATURE with rating of “Excellent”, “Very Good”, “Good”, “Poor”, “Very Poor” and “Not applicable”. The survey has shown that 86% of staff found that their knowledge in sustainable technology improved (majority from “Poor” or “Good” to “Very Good”) after their experience in NATURE. One staff (14%) found his/her knowledge improved from “Good” to “Excellent” after his/her experience in NATURE (Figure 9). All staff agreed that this facility has encouraged more collaborations with industry partners and provided opportunities to develop their capability and competency. By working with industry partners, it helps to keep their professional knowledge and skills in sustainable technology up to date. The effectiveness of the survey for staff can be improved by sending to more staff involved within and across different schools which the team are looking to improve in this area.

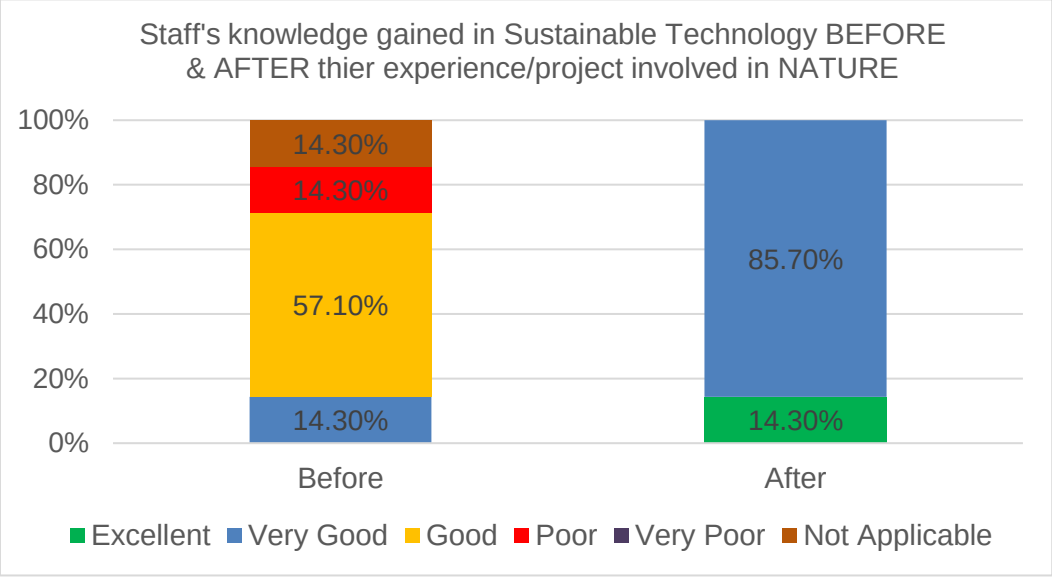

Figure 9: Staff survey on knowledge gained in sustainable technology before and after their experience/project involved in NATURE.

CHALLENGES

There has been several challenges faced in the set-up and running of NATURE. The main challenges faced were: i) being able to focus on selective industry current technologies suitable for training within the confines of the 6 m x 9 m engineering workspace; ii) management of resources in different technologies and skillsets; iii) as well as preventing misuse of the facility.

To set-up and run an interdisciplinary and multidimensional engineering workspace is not easy as it involves a lot of resources. It is important to show the engineering workspace is aligned with the needs of the emerging field identified as important to Singapore. There are various sustainable technologies available but not all can be housed within one engineering workspace. Selection of suitable sustainable technologies which aligned with the needs of emerging field and module outcome are thus important. Technologies proposed were reviewed and selected based on the importance to industry and the ability it can be translated into the training for our students.

With several stakeholders involved in the facility, planning and management of the resources can be a challenge at times, requiring guidelines, procedures and rules to be set in place for the effective running of the facilities. Maintenance of the hardware and facilities and training in the proper use of the facility are very important elements to ensure the success of the facility. These challenges were minimised by creating shared responsibility of all parties involved as well as by enlisting the help of student assistants in the running of the facilities. We employed student assistants who were made on an hourly basis in assisting with the maintenance of the facility. Students involved in the Young Researcher Programme also provided assistance in managing the resources. Staff involved in each field of work were also responsible in their area

of work. For example, staff from the School of Chemical and Life Sciences involved in Aquaponics were responsible for their equipment, plants and fishes housed within NATURE.

Our NATURE workspace has become more popular among students and staff, with many expressing their wish to use the facility in their teaching and learning as it serves as a very useful platform to allow students to appreciate the knowledge learned from fundamentals taught in lectures and provide students with more hands-on experiences to solve real life problems. With this increase in people with different disciplines and activities occurring in NATURE, one of the challenges faced was the invasion of pests. Pests affect the plant's health which could influence the results of the experiments conducted in the greenhouse. To minimise this from occurring, a controlled access to the NATURE was implemented to protect the misuse of facility by unauthorized and untrained personnel. Relevant training is required to be conducted for any staff and student using the facility. Having controlled access increased inconvenience for the people using the facility but was however deemed necessary to prevent greater challenges that can occur from improper use of the facility. Training sessions were conducted on a regular semester basis for new users. Records were also kept on the movement of personnel. The occurrences of pest infestation has been reduced drastically and none have so far been attributed to improper use of the facilities.

One of the key pedagogical parameters important in the setting up of this workspace was to understand the impact this workspace has on the outcome of the students. This engineering workspace was set-up just over a year ago, with the initial idea to focus on sustainable technologies for DNMS. Surveys and studies were set-up for students relevant to this area. In this short span of time, there has however been many potential experiential active learning opportunities in other areas and requested by different diplomas and schools. A standardized or a more structured feedback have yet to be established and used by people who have used this facility as part of their teaching, learning or projects from other fields and schools. In order to achieve a more comprehensive study on the effectiveness of this engineering workspace, we are currently are in the process of developing a suitable feedback that can be used prior to and as part of the training or projects which will cover all users in NATURE.

CONCLUSION AND REFLECTION

This paper has described how a new engineering workspace (NATURE) has provided inter- and multidimensional Interdisciplinary learning opportunities for students from different disciplines. This paper has also shared how NATURE is used as a platform to integrate applied sustainable technology research into the curriculum of the Diploma in Nanotechnology & Materials Science, and allow lecturers, students and industry partners to work collaboratively on multidimensional interdisciplinary applied research projects. The pedagogy approaches applied are aligned with Standard 6, 7 and 8 of the CDIO standard, where an engineering workspace is set up to promote active and integrated learning experience for students.

Having various sustainable technologies under one roof is challenging but yet provided an active experiential learning for various diplomas and indeed a multidimensional

Interdisciplinary platform which benefited students with different backgrounds. Based on the students' feedback, this engineering workspace has met its objective by providing more hands-on learning experiences and opportunities for the school in implementing integrated learning. In addition, this workspace has encouraged more industry collaborations which allow the students to work on real life problems.

There are various challenges faced when setting-up and in the running of the operations of this engineering workspace. Some of these challenges in resource management has been overcome with a structured plan. A detailed study on the impact the workspace has on the outcome of the students from various disciplines has a yet to be conducted but has been planned.

Overall the experience with NATURE has been positive and are welcomed by all students, staff and industry partners. We will continue to document the results of implementation to formulate a more detailed study on the effectiveness of using this engineering workspace as part of our teaching and learning pedagogy.

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Appendix A: Survey conducted in paper format

Nanyang Polytechnic

For *NYP students* Only

SURVEY FOR NATURE RELATED ACTIVITIES

Enrolment Year : _____ Diploma : _____

Name (Optional) : _____ Sex : M / F E-mail (Optional): _____

1. How do you rate your knowledge on Sustainable Technology and Technology related to Agriculture before your experience in NATURE?
   [ ] Excellent [ ] Very Good [ ] Good [ ] Poor [ ] Very Poor

2. What kind of activities were you involved with NATURE ? (You can select more than one)
   [ ] Class [ ] Project [ ] Interest Group [ ] Club/Committee [ ] Others : _____

3. How much increased knowledge and hands-on experience did you gain compared to before your activities related to NATURE?
   [ ] Significant [ ] Reasonable [ ] Marginal [ ] Not at all

4. How do you rate the usefulness of the experience gained at NATURE with providing hands-on experience in your activity?
   [ ] Excellent [ ] Very Good [ ] Good [ ] Poor [ ] Very Poor

5. If you have used NATURE for a classroom activity, did the practical session in a realistic greenhouse setting in NATURE help with the understanding of the concepts taught in class?
   [ ] Yes [ ] No [ ] No Difference

6. If you have used NATURE for projects, did NATURE provide a useful facility for your experiments and prototyping of your project?
   [ ] Yes [ ] No [ ] No Difference

7. Did the activities you have done in NATURE motivate you to want to learn more or select a project in a relevant area of Sustainable Technology or Agronomy?
   [ ] Yes [ ] No [ ] No Difference

8. Would you encourage your friends to join activities in NATURE?
   [ ] Yes [ ] No

9. Any additional comments?

_____

_____

_____

BIOGRAPHICAL INFORMATION

Chee Siaw Soon, is a Lecturer in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. She is involved in teaching several areas of materials science and conducts research and industry collaborations in the field of polymeric nanocomposite for sustainable technology and applications.

Eunice Goh Shing Mei, Ph.D. is a Lecturer in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. She is involved in teaching materials science and engineering subjects. Her main interests are in the areas of educational research and innovation in materials applications.

Hannah Gardner, Ph. D. is a Lecturer in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. She is involved in teaching several areas of materials science and conducts research and industry collaborations in the field of functional nanomaterials.

Wang Yadong, Ph. D. is a Lecturer in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. He is involved in teaching several areas of materials science and conducts research and industry collaborations in the field of nanomaterials for sustainable technology and applications. He has published over 50 top quality international journal papers.

Leonard Loh, Ph. D. is a Senior Manager in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. He is the Course Manager for the Diploma in Nanotechnology & Materials Science, overseeing the design and implementation of the diploma programme. He is also involved in the area of research in the field of Nanomaterials for sustainable technology.

Dr Choo Keng Wah is a Deputy Director in the School of Engineering. He is actively involved in industry project development and management, research and development project, commercialization of IPs, engineering education benchmarking, education quality assurance and accreditation.

Corresponding author

Ms. Chee Siaw Soon
Nanyang Polytechnic
180 Ang Mo Kio Ave 8
Singapore 569830
+65-65500942
Chee_Siaw_Soon@nyp.edu.sg