Young Researcher Programme: An Inquiry-based Learning to Cultivate Innovation and Research Mindset

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ABSTRACT

'Students as researchers' is an active pedagogy emphasizing the process of student research and inquiry. When students practice inquiry, it helps them develop all the critical skills needed for the 21st century which include problem identification, problem-solving, critical thinking, team working, data analysis, scientific reasoning, decision making, etc. Similarly, a programme known as the Young Researcher Programme (YRP) has been implemented in the School of Engineering at Nanyang Polytechnic, Singapore since 2017 to nurture students' innovative spirit and develop capabilities in conducting research.

In the YRP, students are to form their own teams that consist of members who are from different years of study and engineering disciplines. The purpose is to train students to find ways to collaborate, learn and share knowledge and skillsets with a diverse group of members in the team. The team is then required to conduct independent research, integrate ideas from different resources, support their ideas with evidence, conceptualise and apply relevant principles in designing the experiments or products, implement them under staff supervision, and evaluate the validity and reliability of their conclusions. As the YRP is conducted beyond the formal curriculum hours, students are not bounded by the requirement of the curriculum and are free to work on research projects that are of interest to them. Students in the YRP are also given ample opportunities to attend training and seminars, as well as participate in industry visits.

This paper describes how the YRP exposes students to a culture of inquiry-based learning starting from as early as their first year of study at the Polytechnic. This paper also discusses the effectiveness of the YRP in inculcating a research mindset among the students and the usefulness in tracking their individual progress in YRP until their final year of study in the polytechnic. Finally, this paper highlights the challenges faced and provides recommendations for future enhancement of the YRP.

KEYWORDS

Young Researcher Programme, inquiry-based learning, collaborative learning. Standards: 8. Active Learning

Notes: 1) In the context of Nanyang Polytechnic, 'course' refers to a 'diploma' while 'module' refers to a 'subject'. For example, Diploma in Biomedical Engineering is a course; Mathematics is a module.
2) 'Multidisciplinary' approach refers to the integration and application of knowledge from different specializations within the same discipline, for example combining the knowledge from the fields of bioengineering with nanotechnology and material science.

MOTIVATION

The School of Engineering, Nanyang Polytechnic (NYP) offers courses in specialized training for youths who have completed secondary school (or equivalent) studies. The completion of this course of 3 years will lead to the award of a diploma, for example, a Diploma in Biomedical Engineering or Diploma in Nanotechnology and Materials Science. Thereafter, a graduate from the course typically enters the workforce as a professional or continues to pursue an undergraduate study at the university.

In response to the shifting expectations of a young professional entering the workforce, and as well as pursuing a university education, the Polytechnic redefined the education emphasis, to one that incorporates present and future industry needs. The intention is to imbue graduates with the following attributes: professionally proficient, competent in 21st century skills, innovative & enterprising and socially responsible (figure 1).

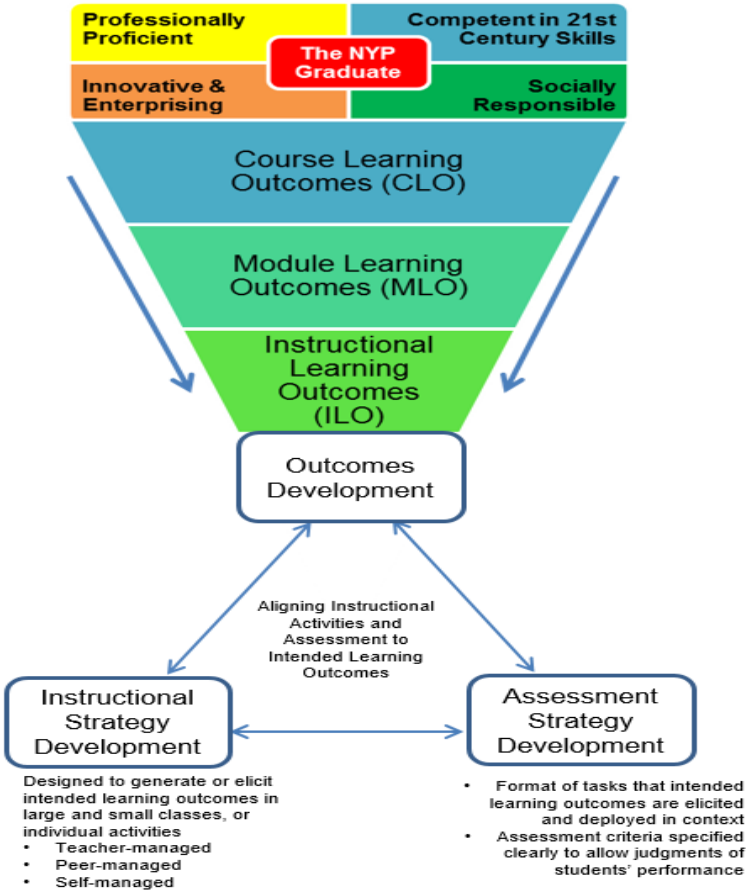


Figure 1: A redefined education emphasis using an outcome-based approach in designing curriculum in Nanyang Polytechnic

Consistent with the Polytechnic's redefined emphasis, the School of Engineering revamped existing curriculum (Choo, et al. 2015) to be consistent with CDIO principles and guidelines (Crawley, et al. 2007). The revamped curriculum is focused on an outcome-based teaching strategy. For example, the module learning outcomes are a subset of the course learning outcome.

There are modules which do not have prerequisites, while others build on the knowledge taught in the prior semester (for example, Mathematics 1B extends the knowledge taught tin

Mathematics 1A). With regards to the current methods of lesson delivery, there is a variety of styles, including the traditional face-to-face approach, and/or flipped-classroom approach. Certain modules have also incorporated mini-projects, where students work individually or in small groups on projects which are devised to allow students to apply the knowledge taught in the module. By and large, the activities mentioned above take place within the module (i.e. students assigned to a mini-project would invariably be from within the same class taking that particular module), or within the same cohort at best (i.e. students assigned to a mini-project might be from different classes, but the classes still take the same module).
Clearly, in this teaching pedagogy, these aspects of active learning can be improved:

- there is no collaboration between students of different courses. Because of the current curriculum structure, it is not possible for students to work on projects where they are grouped with other students from other courses. This curriculum structure inherently reinforces the "silo" mindset amongst students

- there is no possibility of integration across modules, even within the same course. For example, a project with the title of "using films to enhance plant growth" will require knowledge of materials science and statistics

- there is no collaboration between students of different years within the same course. It is not possible to form a project team with say a final year student as the team leader, with the team members from first- and second-years

- project objectives assigned inevitably must conform to the module outcomes. There is no scope for exploring areas outside of module curriculum, but are still related to the module

- more platform to enhance research, innovative and enterprise skillsets before their final year project which is in their formal curriculum

- other constraints like curriculum time, or student mindset ("if it is not assessed, I do not want to pursue this")

To address some of these issues, particularly point 1 above, a new approach was implemented in 2016, called "Integrated Multi-Disciplinary Project" (or IMP in short) (Vinayak Prabhu, 2018), In this new approach, students from different courses are grouped to tackle a project. For example, a team of 4-5 students may comprise of students from Diploma in Biomedical Engineering, Diploma in Nanotechnology and Materials Science, and Diploma in Electrical Engineering (to tackle the various technical aspects of the project). This IMP is graded and has a heavy weightage in the computation of a student's Grade Point Average (GPA). IMP is only implemented in the final year where students only get to work in multi-disciplinary teams when they have no exposure in the first 2 years of their Polytechnic education.

METHODOLOGY AND IMPLEMENTATION

"Young Researcher Programme" (or YRP), was conceived in 2016 to address the gaps identified in the preceding paragraph. This programme is jointly administered by 2 courses, namely, Diploma in Nanotechnology and Materials Science and Diploma in Biomedical Engineering. This programme is conducted outside of curriculum time and is targeted at students who wish to enhance their research, innovative and enterprise skillsets in areas not already covered by the curriculum. There are also a series of activities to complement the programme. Students from any of the courses within the School of Engineering are eligible to participate in this programme. This is of the key features of the programme: allowing a multi-

disciplinary collaboration among the students, unconstrained by curriculum limitations. This pilot scheme is run outside of the curriculum in order to test out the interest of students and also allow the school to evaluate the outcome of this programme. YRP project is different from Final Year Project or Capstone Project which done at the end of the student's final year and it is within their formal curriculum. The project was done by the students usually integrates and synthesizes what they have learned throughout their years of study (P.J. Armstrong, 2005).

Potential student participants are given a list of projects and asked to indicate their preference. Subsequently, a project team is formed based on sign-ups. The projects are scoped to be completed over 1 semester (i.e. 6 months). As a form of commitment to the success of the project, students are advised to spend a minimum of ten (10) hours on the project, and this is outside of curriculum time. The activities that are counted in this time commitment include briefings, meetings, experimental work, etc, and the students typically maintain a timesheet.

In each project team, there is usually a mix of students from different courses, and from different years. Student Mentors will be assigned to the team, based on his or her track record of competency, who will guide the team in the research project. Other administrative matters are managed by Student Programme Leaders. All students who are involved in this programme are awarded Co-Curricular Activity points in the area of leadership, participation, enrichment and service depending on their role. Roles and responsibilities of all stakeholders are shown in Table 1.

Stakeholder	**Roles and Responsibility**
Course Manager	• Champion of the programme
Staff in Charge for YRP	• Staff advisor of the programme. • Recruit and manage Student Programme Leader • Collate research project submission from staff • Organize programme activities
Staff	• Propose and submit research project • Guide student participants in the research project.
Student Programme Leader	• Facilitate and coordinate programme activities. • Assist staff in managing student roster or activity (If any). • Recruit Student Participants. • Publicity of programme activities. • Communication with Student Participants.
Student Participant	• Work on research project (min of 10 hours) • Participate in programme activities such as company visit, seminar etc.
Student Mentor	• Guide and train student participant in the research project. • Monitor student's work • Update staff progress or status of the project.

Table 1: Roles of the various stakeholders in the YRP

In the Young Researcher Programme, research projects are proposed by staff. While the staff is responsible to scope the project and define the project objectives, staff involvement in the project execution is minimal. This is to facilitate active learning in this programme. Keeping in mind that since this project is outside of the curriculum, and therefore not graded, there is thus more leeway for students to take ownership of the research process, explore and innovate. In short, there is no penalty for not succeeding.

From the onset, students are guided by staff to plan, design, implement and test their ideas to achieve the project objectives. Thus, the students carry out the following activities, as illustrated in figure 2.

Plan:
Based on the project objectives, facilities and staff resources, divide the overall project into subtasks, plan the activities and project schedule accordingly. Given the individual interest and competency, define the roles of each member and the deliverables

Design:
For subtasks, where experiments need to be carried out, the students are guided into designing the experiments, maintaining consistency with the project thesis. This could be modifying existing laboratory manuals, or if there is no precedence, then carry out literature research and then developing the experimental design. The experiment design has to be approved by staff before actual experiments are carried out. Experiments are carried out at this stage, initially under the guidance of staff. More often than not, the experimental design may have to be refined. This is again carried out by the students in consultation with staff.

Implement:
Transformation of design into the delivered solution or product, including manufacturing, software coding, product testing, and validation.

Test/Operate:
Use the implemented solution or product to solve the problem or deliver the intended value.

This process of active learning benefited both student participants and student mentor. Apart from technical skill development for student participants, soft skills such as mentoring and leadership skills are also developed in student mentor Student participants will be able to progress and work as a student mentor or student programme leader in next semester.

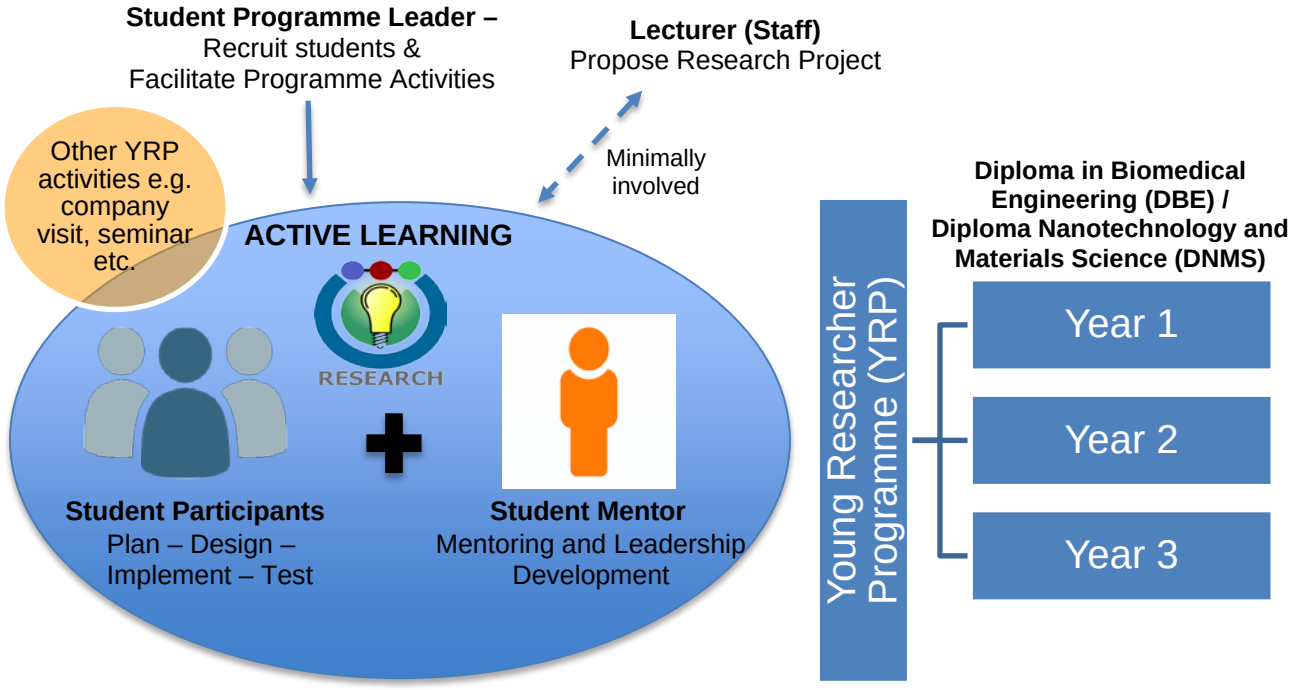


Figure 2: This figure shows YRP is outside of the formal curriculum. Students from DBE and DNMS from a different year of study will be working together in the research project. Active learning is designed in this programme which strives to involve students (both student participants and student mentor) in the learning process. Student Programme Leader helps to

recruit students and facilitate programme activities whereas the involvement of staff in the research project is minimal.

Observations

YRP commenced on 2017 Semester 1. In one of the research projects, students were to measure the electrical conductivity of polymer filaments used in 3D printing. This team of students were from a mix of courses, and some did not possess any knowledge in materials science. The students prepared samples by doping graphene into two types of polymer which were Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS). They found graphene doped ABS filament possesses extremely high resistance which decreases over time as current flows through it. They also found that the thicker the sample, the higher the initial resistance.

The project team leader was a first-year student from Diploma in Nanotechnology and Materials Science (DNMS), who has the necessary competency in materials synthesis and characterization. Fellow team members from the Diploma in Biomedical Engineering (DBE) contributed by performing the Computer Aided Design (CAD) and 3D printing. Thus, the students were exposed to knowledge and hands-on experience which are outside of their formal curriculum in biomedical engineering.

Figure 3: Graphene doped ABS samples prepared by YRP students with no materials science background.

YRP is also served as a platform to support industrial collaboration and those projects often address real-life problems. The research work in the project is usually just a bite size of the entire industrial project. They are usually simpler and less time-consuming. An example will be to study light output for each duct of 3M Channel Light System. The objective of this project is to study the light output of each light duct of 3M Channel Light System with a given amount of input and compared with a conventional lighting system. Three year 2 students from DNMS conducted the measurement using a spectrometer and monitor the data collected during their break. The result has shown that 3M Channel Lighting System has a reflective light duct which will reflect the light emitted from the LED at each end of the duct across, with higher luminous efficacy as compared with the conventional lighting system. Students learned how the 3M Channel Lighting System emits more lights across a larger area compared to a conventional lighting system.

Another research project is to study how N/P/K (Nitrogen/Phosphorus/Potassium) value of different fertilizers can affect the growth of the plants. There are companies who passed their fertilizers to the school and they are interested to know how their fertilizers work using the vertical farming system in the school. Three year 2 students from DBE and two year 2 students from DNMS with no background of farming, learned and worked together in the greenhouse to conduct this study. Two types of fertilizers with different amount of N/P/K values (17/11/10 vs 8/8/8) were tested out. The results show that lettuce grew using a fertilizer with higher N/P/K value has higher leaves height, width and weight as compared to the fertilizer with lower N/P/K value. Students learned the higher nitrogen composition in fertilizer with higher N/P/K value does promote leaves growth as lettuce is a leafy plant.

In order to showcase students' research in this programme, technical poster presentation was organized (see figure 4). It served as a platform for the students from different projects to exchange their ideas and also recognize their efforts in the programme. Lecturers and final year project students were invited as a judge to vote for the best project. This had also provided an opportunity for the final year project students to apply their technical knowledge learned throughout their three years of study in NYP to evaluate the depth and value behind each project.

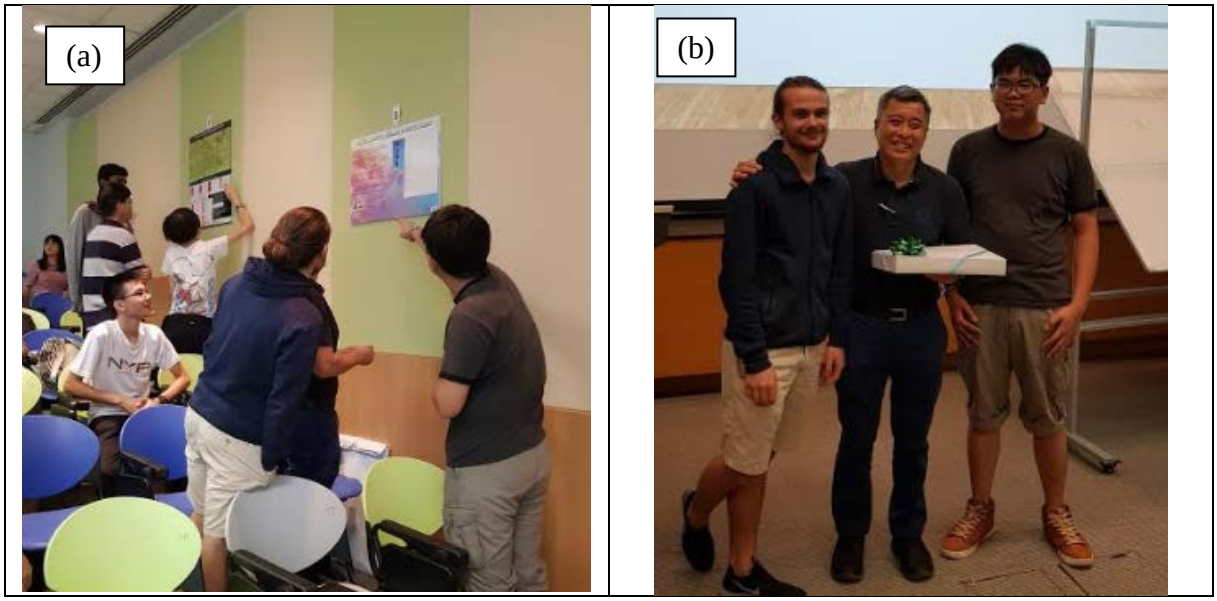
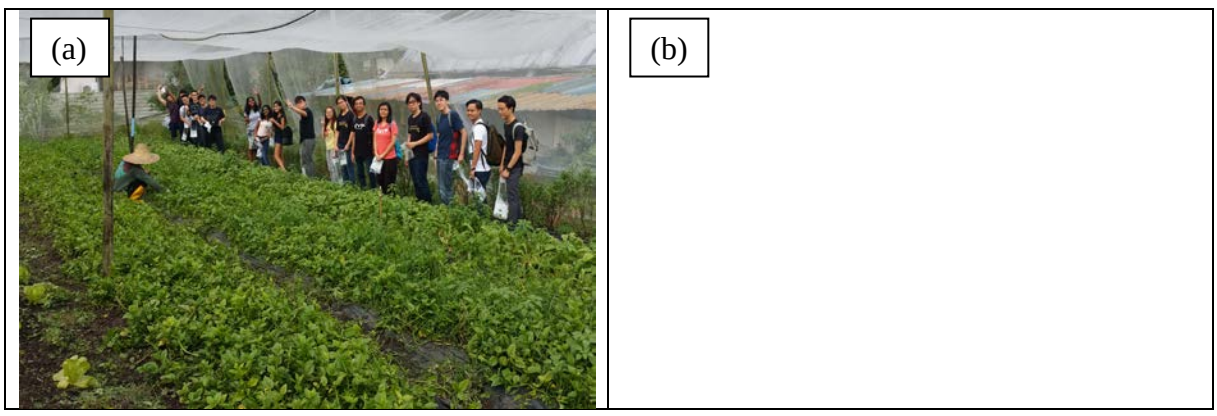


Figure 4 (a) shows students were presenting their technical poster to lecturers and peers. (b) Prize presentation to Best Project award winners.

Apart from just research projects, activities such as company visit, excursion and project exhibition were also organized to enhance students' learning experience in this programme (see figure 5). Some activities are specially organized for YRP students or they have the priority to join those activities. These programme activities are also an active learning for the students. For example, third-year students from Diploma in Nanotechnology and Materials Science had organized a Smart Materials Exhibition to showcase their projects on using smart materials to develop an interactive game. Students from the YRP programme were invited to the exhibition and learned about the smart materials by playing the game with their seniors. The game was interactive and hence the students had fun yet learned about smart materials. This also served as a platform for students in different levels (first, second and third year) or background to exchange knowledge and ideas.



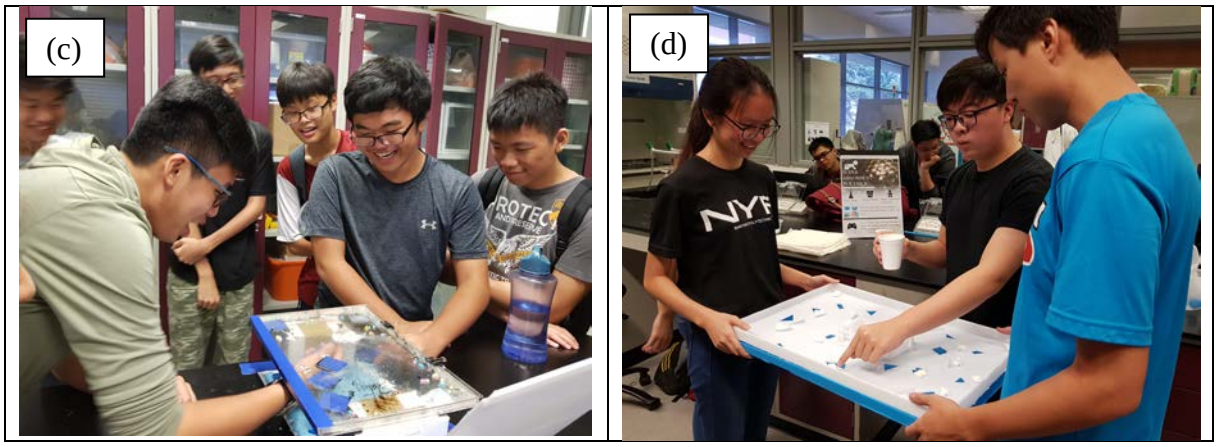
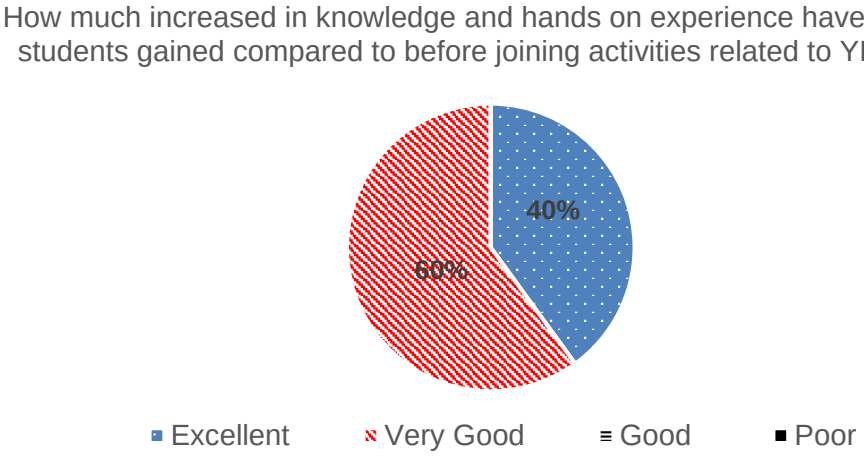


Figure 5 (a): Students visited local farm. (b) Company visit to 3M Customer Technical Center. (c) & (d) YRP students participated in Smart Materials Exhibition which organized by third year students from Diploma in Nanotechnology and Materials Science.

RESULTS AND FINDINGS

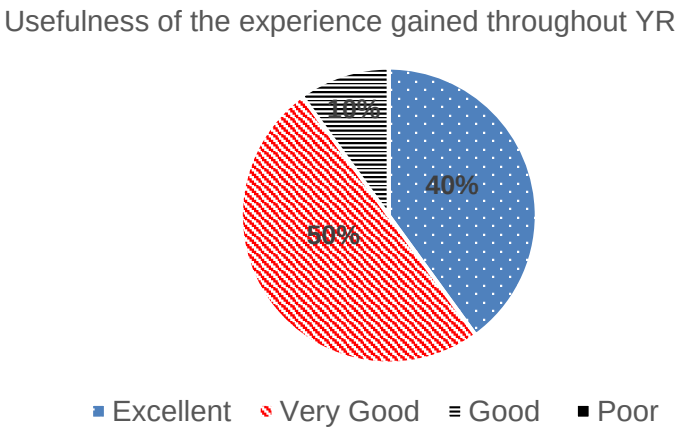
The Young Researcher Programme has been running for three semesters (2017 Semester 1, 2017 Semester 2 and 2018 Semester 1), a total of 68 students participated. An online survey was conducted in 2018 Semester 1 to gather feedback from students how well the programme is received by the participants. A few questions were asked in the survey. Total of 10 students joined the programme in 2018 Semester 1 and all of them participated in this survey.

Students were asked how much increase in knowledge and hands-on experience they gained after joining the activities related to YRP compared to before. The rating given to the students is “Excellent”, “Very Good”, “Good” and “Poor”. In this survey, 40% of students rated their knowledge and hands-on experience gained “Excellent” and 60% of students rated “Very Good” (see graph 1).



Graph 1: Students’ perception of the level of knowledge gained though YRP

The students were asked to rate the usefulness of experience gained throughout the YRP programme with ratings categorized into “Excellent”, “Very Good”, “Good” and “Poor”. 40% of students rated the usefulness of experience gained throughout this YRP “Excellent”, 50% of students rated “Very Good” and 10% of students rated “Good” (see graph 2).



Graph 2: Students' perception of the usefulness of YRP

These have shown that the research activities in YRP have brought a positive impact to students' learning. The active learning which brought a lot of hands-on experience gained via this YRP played a part in developing a more professionally proficient graduate. Students found it useful as the skillset learnt can be applied in their study or final year project. This could help to nurture student's critical and inventive thinking which are essential skills in 21st century. In addition, all students who participated in the survey would encourage their friends to participate in YRP. There were also students who participated repeatedly in this programme. The school hopes by encourage more students to participate in this programme so that more students can develop capabilities in conducting research and also nurture students' innovative mindset.

There were some other comments left by students such as they appreciated the mentoring from both student tutor and lecturer. As the students researched on the topic that they were not familiar with or not learnt from their diploma, guidance from the tutor were very useful to them. Besides, students also commented they hoped to form their own team next time as it is easier to find a common time slot to discuss and work on the project with their teammates. However, staff also shared with them the benefit of doing a project with students from another discipline.

From the survey and by talking to students or staff involved in this programme, we discovered an area for improvement. In the survey, students were asked whether the project in YRP motivated them to learn more about the topic that they were researching. Eight (8) students indicated "Yes" but two (2) students indicated there was no difference. This could possibly be due to the project assigned to the students were not their first choice or it could be from the same course of study. Additionally, 20% of the students felt that the program leaders who are students facilitating or coordinating could have done more to facilitate the progress of the project. By talking to the staff and students, we found that some staff contact the YRP participants directly, but some staff depended on the student programme leader to contact the YRP participants. This might create miscommunication between these three parties. Moving forward, we will encourage the staff to contact the YRP participants directly to minimize unnecessary miscommunication.

CHALLENGES

As mentioned in the results and findings, miscommunication may be part of the challenges in this programme. This programme involved staff, student programme leader and student participants. The role of student programme leader is created to facilitate or coordinate the whole programme which including the recruitment of students, publicizing programme activities and communicating with student participants. As the student programme leader is not part of

the project team member, they do not lead the project, and this could lead to some deliverables of the project not being met. The leadership for the project or more initiatives should come from the student participants. This can be minimized by communicating the expectation to all student programme leaders and also student participants. Additionally, the student programme leader can appoint a team leader for each team.

One of the challenges faced is to get sufficient mini-research projects in this programme. To mitigate this, suggestion such to encourage all staff take turns to submit mini-research projects every semester. Otherwise, students can also brainstorm and propose their research project under the staff's guidance in order to ensure the feasibility of the project. Lastly based on staff and student programme leader's feedback, it was observed that students were more active in the YRP research project during the beginning of the semester when they were not heavily loaded by their course work or projects in their formal curriculum. Therefore, the golden period to get the students to work on their YRP project is at the beginning of the semester. Therefore, setting a timeline to complete the research project before the mid of the semester will be helpful for both students and staff.

Another challenge is how to better measure students' performance in terms of improving their hands-on experience after participated in YRP compared to those who did not participated. This can be evaluated for students who participated twice in YRP and student's skillset can be evaluated or assessed based on the increase in difficulties in second YRP project. In addition, it may be assessed via some modules which require more hands-on and practical skills. However, skill-set learned from different YRP project will be different, therefore selecting a module to evaluate students' improvement on hands-on skill need to be assessed carefully to study the relevancy.

CONCLUSION

Active learning which involves students' participation rather than passively listening in the learning process has been proven effective in students' learning. Young Researcher Programme (YRP) has provided a platform allowing a multi-disciplinary collaboration among the students, unconstrained by curriculum limitations to learn by working together. Staff involvement in the project execution is minimal. This is to facilitate active learning in this programme. All projects in YRP is outside of the formal curriculum and are not graded which meant to give students more space and ownership in the research process to explore and to innovate.

The overall experience of the students who participated in this programme is positive. Students found they gained more knowledge and hands-on experience after joining this programme. They also found the knowledge gained and hands-on experience are useful which can be applied in their study or final year project. All students agreed to encourage their peers to participate in this programme as they were benefited from this programme. This programme helps more students to develop capabilities in conducting research and also nurture students' innovative mindset.

However, this programme can be improved by overcoming some of the challenges mentioned above. Challenges such as communication between the students and staff can be improved by setting the right expectation to all students and encourage staff to directly communicate to the students. In order to have a more meaningful research project, setting timelines to complete the projects before the students are heavily loaded by their study and projects from their formal curriculum will be helpful. To bring the active learning of this programme to a higher level, students can also brainstorm and propose their own research projects.

The programme has been running for three semesters and the school is seeing the positive impact brought by this programme. Students were directly involved in the research project and actively learning outside of their formal curriculum which is not graded and results in a less stressful environment. Students were also given a chance to work with other students with different backgrounds which has also encouraged more inter- and multi-disciplinary learning. The school hopes to encourage more staff and students to participate in this programme in order to enhance the diversity of the projects as well as the programme activities.

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BIOGRAPHICAL INFORMATION

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