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In this issue:

Learning in Groups

Enhancing Learning in The Laboratory

Note from the Editors

In *CDTL Brief's* first installment for 2012, we are pleased to have colleagues share their experiences of incorporating group-centred learning activities in their classes as well as measures they have adopted to enhance their students' learning in the laboratory.

In their book *Learning in Groups* (2007), Jaques and Salmon inform us that this approach "has a critical role to play in the all-round education of students". They add that "groups are not merely a valuable vehicle for learning about the skills and concepts of a subject discipline, but are also a way of learning about groups: developing abilities in cooperative work for later life" (pp. 2).

Indeed, what the contributors to the first section of this issue have in common is their recognition of the benefits of including this "valuable vehicle" in their classrooms to enrich their students' learning journeys, even as they examine different facets of this approach. For instance, Dr Thian Eng San (Dept of Mechanical Engineering) shares his experiences of adopting the project-based teamwork approach and how it has enhanced his students' capacity for self-directed learning (pp. 4). Similarly, Dr So Wing Chee (Dept of Psychology) has her students form groups from the beginning of the semester, as it provides what she calls a "friendly platform" for participation in classroom activities. She also emphasises the importance of collaborative learning across the groups to ensure class cohesiveness (pp. 2). Meanwhile, Ms Christine Teng applies a tutor-led small group approach to debrief her final year Pharmacy students following role-play sessions in which they dispense mock prescriptions and provide patient counseling (pp. 7). In this case, the tutors give immediate feedback to each group and the students receive more individualised input about their performance.

In the next section, Dr Aaron Danner (Dept of Electrical & Computer Engineering) shares his strategy of making the submission of laboratory reports optional to minimise the risk of plagiarism (pp. 10). His article details the benefits and challenges he faced in adopting this approach. Meanwhile, Dr Chew Eng Hui relates how incorporating demonstrations and hands-on sessions in the laboratory has helped her second year Pharmacy students grasp complex molecular biology-related concepts such as recombinant DNA and protein technology (pp. 12). In both articles, it is clear these strategies have significantly enriched their students' learning journeys.

Reference

Jaques, D. & Salmon, G. (2007). *Learning in Groups: A Handbook for Face-to-Face and Online Environments.* Abington, Oxon.: Routledge. ■

Collaborative Learning Within and Across Groups

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My teaching philosophy is deeply influenced by Lev Vygotsky, a social developmental psychologist. According to his theory, social interaction plays a critical role in the development of cognition (Vygotsky, 1978; Wertsch, 1985). Specifically, a range of cognitive skills often develops in the context of peer collaboration. Although his theory focuses on cognitive development in early childhood, I find that it can well apply to adult learners who acquire new skills and concepts. While teaching Psychology in NUS, I have been practicing Vygotsky's principles in my modules by encouraging students to learn through collaborating with their group members (i.e. collaborative learning).

Collaborative learning is increasingly popular in university settings nowadays. It benefits learning at least in the following ways (Davis, 1993). First, it provides a friendly platform to all students by encouraging their participation in classroom activities. In addition, it enhances their critical thinking skills in relation to the course materials and helps them to retain the information longer. More importantly, students could further develop their unique strength and expertise during group discussions.

Yet collaborative learning requires the lecturer to do careful planning. In order to enhance group-learning outcomes, it is advisable that students form groups at the beginning of semester and build up collaborative group work throughout the semester. Working in the same groups for a sustainable period allows them to establish team spirit, hence increasing enthusiasm for learning course materials. However, working in the same small groups for an entire semester might also lead to the formation of isolated cliques, which can weaken class cohesiveness. Therefore, it is crucial to maintain collaborative learning within *and* across the groups. In this article, I will discuss the procedures that I have adopted in order to enhance collaborative learning in an Honours module. There were around 50 students taking this module and most of them were third and fourth year undergraduates.

A month before the semester started, I had posted the syllabus on IVLE so that students would have a better understanding of how much of the classroom work for this module involved collaborative learning. At the outset of the first class, I played a game with students to help them form groups of five to six. The game allowed them to select their own group members. While working with friends facilitates interaction and enhances productivity, it might run a risk of isolating other students (see my discussion about this issue further down the article).

After the students were assigned their respective groups, I explained clearly to them the assignments they should accomplish in this module. Other than the final exam, they had to finish two group projects. For each project, they had to conduct small-scale experiments and present their findings during the lectures. Each group was also required to lead class discussion during the lecture by summarising the assigned readings and raising questions that would stimulate critical thinking in the class.

In a competitive academic environment like NUS, students often have a natural tendency to use their individual efforts to obtain the best grade in class. Thus, some of them might be skeptical about the value of group work. As a lecturer, I addressed the importance of group work and explained why group work was essential in this module in order to provide my students with a complete picture of the learning objectives. More important, I highlighted two main elements of group learning—positive interdependence and individual accountability. In order to achieve group cohesiveness, each student had to be interdependent on each other and he/she should encourage his/her peers in the group in order to attain the same goal. At the same time, each student was also individually accountable for other group members. Thus, he/she should do their fair share of work and master the material learnt in the class. Having said so, some students might still dominate the discussions while a few introverted ones might withdraw from group activities. To minimise such occurrences, students were told that they were to evaluate each other's contribution at the end of the semester by filling in a peer evaluation questionnaire. The questionnaire assessed each member's frequency of participation in group discussions, likelihood of keeping the group focused and contributing to useful ideas, the quality and quantity of work done, and finally, timeliness of the completion of work assigned. Each item was rated on a 5-point scale and the peer evaluation score of each student was counted towards his/her final grade. I also encouraged the class to report any group dynamics they observed in their own groups and promised them that I would carefully look into each case. Throughout the semester, I monitored the collaborative learning process in each group

As stated earlier, working with friends enhanced students' productivity. However, it might weaken class cohesiveness due to the formation of cliques, which may lead to isolation with other groups. In order to address this issue, I asked the class to organise a mini-conference that served as a platform for them to present their project findings. Each group sent one or two representatives to discuss their findings with the other groups. During the discussion, they looked for common themes in terms of their research questions and experimental designs. Groups who conducted similar projects formed a symposium and presented their findings together in the same section during the conference. By doing so, students would gain a better understanding of both their own projects as well as those done by other groups. More important, it strengthened class cohesiveness by extending interaction from the group level to the class level (which is also a kind of collaborative learning).

Overall, collaborative learning serves as an important supplement to the lecture. It not only helps students to master concepts, but also enhances their critical thinking skills. It is truly rewarding when students tell me that the group discussions are inspiring and engaging; collaborative learning has transformed their thought processes and helped them to accomplish more than working alone; and learning with their peers help them to understand their strengths and weaknesses.

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Wertsch, J.V. (1985). *Vygotsky and the Social Formation of the Mind*. Cambridge, MA: Harvard University Press.

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Learning through Project-based Teamwork in Engineering Education

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Philosophy

I strongly believe that teaching is not merely about standing in front of a lecture theatre to convey information so that students can take notes and memorise them. Besides providing students a content-based syllabus with specific guidelines about what they should learn, and what skills and understanding they should value, it is equally important that the educator selects and designs the right combination of reading assignments and class projects. A well-chosen set of learning resources will equip students with the skills that will steer them towards self-directed learning and at the same time, provide them with the opportunity for classroom discussion. Such discussions will inevitably expose students to different viewpoints, develop their oral advocacy, encourage cooperative learning and enhance their ability to retain learned information for a longer period. To support this goal, case studies and/or project-based teamwork (Ngai, 2007) has been incorporated into the syllabus. In short, my teaching philosophy is to provide for all my students an environment that encourages lifelong learning. This article presents an exploratory study investigating the integration of a project-based teamwork approach to teaching and its impact on students' learning.

Methodology

This study was conducted to a class of postgraduate students undertaking the course module ME6505 "Engineering Materials in Medicine" at the Department of Mechanical Engineering, National University of Singapore (NUS) in Semester 2 of Academic Year (AY) 2009/10. The lecture component of ME6505 will cover fundamental knowledge in the biomaterials field to ensure that students start their respective projects armed with the appropriate tools and know-how. Detailed specifications and requirements for the project are outlined and provided to the students at the beginning of the course. All 35 postgraduate students who enrolled for this module participated in this study. The class formed 7 groups, each comprising 5 students, and each group was tasked to prepare a research proposal based on an implanted device. During the study, I assumed the position of a facilitator pointing students towards possible solutions to the problems they were facing in the course of preparing their research proposal. A proposal report of no more than 5 single-spaced, A4-sized pages and a 25-minute presentation to the class were used as a form of assessment, which allowed the students to demonstrate their mastery of the subject material as well as providing ownership of the submission. A feedback questionnaire was administered among the students in order to collect both qualitative and quantitative feedback. The feedback was used to analyse the impact of the approach on students.

Findings and Discussion

It was observed, from the feedback obtained, that the majority of students felt that the project-based teamwork approach has enabled them to learn more about the subject matter, with 34.3% grading the approach as “excellent”, 62.8% as “very good”, 2.9% as “good”, and 0% as “satisfactory” or “poor”. At the same time, they felt that this approach has helped them to better understand the importance of clear presentation and good project management. I shall now look in closer detail at the opinions received from students with regards to this pedagogical approach.

- *Self-learning.* Generally, students felt that the project-based teamwork approach has enhanced and contributed to their ability to learn and has also given them the freedom to learn at a pace they desire, thus making the learning process more enjoyable and meaningful. This feedback is consistent with Ngai’s (2007) observation that one of the benefits of this approach is that students “built up their capabilities to learn independently” (pp. 27).

- *Deep learning.* The ability to engage, involve and develop students to think deeply during the learning process is important, such that they will then appreciate the knowledge acquired and thereby more effectively retain the knowledge gained for a longer period of time. Generally, students felt that the project-based teamwork approach has provided them the opportunity to learn more and in greater depth. From the submitted reports and oral presentations, I am convinced that this approach has indeed helped my students in their learning process since they are able to introduce the latest advancements in the biomedical field, and even some bioengineering concepts and terms that go beyond what the lectures covered.

- *Oral and written advocacy.* Giving presentations and writing reports do not simply mean extracting and copying information from the available resources, but rather it involves having to explain and present the information clearly to the audience. Indeed, the students do have a positive opinion that the project-based teamwork approach does enhance their oral and written skills. When assessing the students’ reports and presentations, I notice that the students have tried their very best to explain difficult concepts and facts in the simplest manner. Furthermore, all the students participated during the oral presentations, and most of them managed to overcome any initial stage fright after talking for more than 5 minutes. Similar results have been found in the study by Ngai (2007), where the project-based teamwork approach helped to enhance students’ communication skills.

- *Time and project management.* The importance of managing time effectively and the ability to work as a team are crucial in the completion of the assigned project since a great degree of responsibility falls to the students. The majority of students felt that this pedagogical approach has indeed helped them to plan their time better and to be better team players. During this study, I did not need to chase after any group to submit their reports. Instead, all the groups submitted their reports punctually, without any requests for deadline extensions. Furthermore, I did not receive any complaints from any of the groups. Basically, they are happy and comfortable working among themselves.

On the whole, students give more credit to the advantages of this pedagogical approach, and were very satisfied with the study. Nevertheless, should this model be implemented again, it is necessary to assign each group a research topic in the beginning of the course so that they will be able to kick-start the project early, rather than spending weeks deciding on a topic of interest.

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Conclusion

I believe there are many pedagogical models that can be applied to one's teaching in order to realise one's educational philosophy. In this study, I have presented the use of the project-based teamwork approach as a pedagogical model in Engineering education. The model is considered beneficial according to the students' perception since it has helped them greatly by enabling them to develop and improve their oral, writing and self-directed learning skills, helped them gain a deeper understanding of the subject matter and enhanced their ability to manage their time and projects effectively. I would certainly encourage other educators to implement this model to their modules (if applicable) since it is clearly a refreshing departure from the current practice of assessment in most universities, i.e. via continual assessment or submitting a term paper. There is nothing wrong with these practices, but students usually tend to memorise, regurgitate and forget what they have learnt after going through many traditional types of assessments.

Acknowledgements

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Using Immediate Small Group Review and Feedback to Enhance Students' Learning

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Nowadays, educators employ various methods to evaluate and provide feedback about their student's work during practical classes. It is evident from the literature that providing feedback on students' work is important as it can "guide, test, challenge or redirect the learner's thinking" (Pellegrino, Chudowsky & Glaser, 2001) and "explains the gap in knowledge and understanding" (Orrell, 2006). Some examples include providing written comments on practical reports which are given back to students and holding debrief sessions, either as a large class or in small groups.

In PR4104 "Pharmacy Practice 3", a compulsory module taken by all final year Pharmacy students, we employ various evaluation methods as this is a special year-long module made up of different segments of practical sessions with the main aim of getting students ready, upon graduation, for real world practice as pre-registration pharmacists. Classes include case discussions, role-play presentations, critical evaluation of journal articles, and so on. In particular, it includes 2 dispensing sessions. At each dispensing session, students are given mock prescriptions to work on. This is an individual effort where students have to review the prescriptions, ensure the prescriptions meet legal requirements and are free of drug-related problems (e.g. potential drug interactions, incorrect dose etc). Where there are such "errors" in the prescription, students are expected to confirm certain information with the "prescribers" or "patients" in order to correct these errors. To make such interventions, students will approach the tutors to conduct a role-play where students act as pharmacists while tutors act as prescribers, patients or caregivers. When the prescription is deemed correct, the student will process the prescription, that is, pack the required medicines, attach the medicine labels and ultimately script out the dispensing of the medications (including patient counselling) on a worksheet provided. At the end of the sessions, student will submit their mock prescriptions and worksheets to the tutor. The worksheet will be graded but not returned to students. Previously, feedback was provided to students through a separate session where the tutors will go through commonly made mistakes with the whole class.

However, the feedback collated from previous years regarding this module has shown that some students felt the sessions were too rushed and stressful; as such, they were not able to fully appreciate the learning objectives. On the other hand, our tutors have also expressed concern regarding the large class size for the debrief session; this is because in such sessions, tutors could only highlight common mistakes made and students may not know how they individually fared for the sessions. Also, the debrief session is usually carried out 1 to 2 weeks after the dispensing session, hence students may not always have a clear memory of what they have done (also since all mock prescriptions and worksheets have already been submitted). Furthermore, not many students were inclined to raise questions during class, possibly due to the large group present.

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Table 1. Differences between the previous and new model of running a dispensing lab.

Previous model	New model
3 prescriptions to be completed in 3 hours	2 prescriptions to be completed in 2 hours
Role-play for conducting interventions only	Role-play for conducting interventions and patient counseling
Large group debrief session held 1-2 weeks after first dispensing session only	Small group review and feedback conducted immediately during the last hour of class for both sessions
Tutors took turns to provide comments at debrief	Student:Tutor ratio of 8:1 during small group debrief
Tutors provided pictures of preparations to highlight common mistakes	Immediate tutor and peer review of preparations by each student
Tutors discussed common mistakes found from the grading of reports	Tutors go through in detail all requirements and learning points for all prescriptions
Students did not get their reports back and may not be aware of mistakes they made	Immediate review of products and reports; students immediately recognise which areas require improvement

In view of the feedback provided by students and faculty, we implemented a different model of running the dispensing sessions in AY 2010/11. The differences are listed in Table 1.

The most important change was the implementation of a tutor-led small group review and feedback component at the end of each dispensing session. One tutor will carry out small group debrief with 7 to 8 students. During the small group review and feedback, students compared their preparations and the tutor was able to review each preparation and immediately point out mistakes and suggest areas for improvement. Tutors also discussed the steps involved in processing the mock prescriptions (including correction of any errors detected). A patient counselling role-play was also carried out and feedback was provided by tutors and peers.

A survey was conducted at the end of the 2 dispensing sessions that implemented immediate review and feedback in small groups. Out of a class of 107 students, 102 (95%) participated in the survey. The results are shown in Table 2.

Table 2. Student's evaluation of the immediate small group review and feedback.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Time allocated for each session was adequate	10	22	31	33	6
I benefited from feedback given to me by the tutors during role-play	2	1	13	58	28
Small group debrief immediately after prescription preparation enhanced my learning experience	0	1	2	57	42
Small group debrief helped me to learn areas I've done well and areas where I need improvement	0	1	6	61	34
Tutors were approachable for clarifications during small group debrief	0	0	4	54	44

Overall, the sessions were well received by students who provided much positive response. Most students (> 80%) felt that they benefited from feedback given by the tutors during role-play (86/102). Most of them agreed that having the small group debrief immediately after prescription preparation exercise enhanced their learning experience (99/102). They felt that with the small group debrief, they were able to appreciate areas they had done well and areas which needed improvement (95/102). Most students felt that the tutors were approachable when they required clarifications during the small group debrief (98/102).

Although the number of prescriptions assigned was reduced to 2, the time allotted to complete the prescriptions was also reduced (from 3 to 2 hours), and 30% of students surveyed felt that the time allocated for each session was inadequate. Some students felt that more information about the sessions could be given beforehand so that they will know what to look out for and be able to be more effective at the dispensing sessions. As many tutors are involved in this small group review and feedback component of the module, some students commented that different tutors may have different debriefing styles and may also approach the prescriptions differently. However, this may be inevitable because in real life, different pharmacists may also handle situations differently.

In general, the tutors were pleased with the new model as it allowed them to have more interactions and teaching moments with their students. Students were also more ready to seek clarifications and share their learning experiences in a small group environment.

Going forward, we will continue to adopt this new model for the dispensing class in PR4104. One possible improvement is to include a briefing session to be held the week before the dispensing class, which will bring students through the steps involved in reviewing a prescription (without having to actually pack the medicines). Students may then feel more prepared and less "lost" at the actual dispensing class.

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How to Prevent Plagiarism of Laboratory Reports: A Case Study in Analog Electronics

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Plagiarism is not only a problem in the social sciences or writing courses where students must write essays; it is also a problem in engineering and science courses, and encompasses not only writing but also technical projects and laboratory experiments. The subject to be addressed in this essay is the issue of plagiarism in laboratory reports and projects, where data is often identical and it would be impossible for a teacher to tell a plagiarised report from an authentic one. How can engineering teachers tell when a student has built his/her own project? If a laboratory experiment in an electronics module calls for a particular circuit to be designed and measured, it is only natural that the dataset generated by different students would be almost the same regardless of whether a student has copied the data from his/her peers or not. If a laboratory module requires all students to submit laboratory reports, then occasionally, in the past, students have resorted to copying data from previous years' or peers' laboratory reports (or from Wikipedia for the introduction/background section), and this is especially true in cases where students are late or ill-prepared for a laboratory session. How these occurrences were eliminated will be described in this article.

In the case of EE3407 "Analog Electronics", students build circuits such as amplifiers and radio transmitters. Even for students of electrical engineering, these types of devices are difficult to build. They consist of a large number of components and students have only three hours in each laboratory session in which they must finish building everything while troubleshooting errors along the way. Traditionally, a write-up of some sort is required at the end of every laboratory session. Unsurprisingly, it is observed that there could be a correlation between a student's ability to create a properly-working circuit and a student's ability to write a proper laboratory report. This correlation can be exploited to improve the quality of education.

Students with poor writing skills but good laboratory skills can be unduly punished by a grading system that relies solely on grammar. A student who copies from Wikipedia for a laboratory report for example, may hand in something with flawless English, whereas a student who spends time trying to understand the material and writing in his/her own words may hand in something that, on first glance, seems to be inferior but actually deserves more credit. This is not to say that attention should not be given to proper writing, but that both technical accomplishments and writing should be considered when grading a student's report. The solution, implemented in EE3407 over a 2-year period and found to be effective, was to take the extreme step of making laboratory reports optional. Here is exactly what was done:

a. Students are assigned a laboratory with two parts, an easier part and a more challenging part worth 80% and 20% of the grade respectively.

b. Students must finish building the circuit during the laboratory session or receive no points. Points are awarded if the circuit works but no points are awarded if the circuit does not work.

c. If a student did not get his/her circuit to work but did attend the laboratory session, he/she can submit a typewritten laboratory report at a later date explaining exactly why his/her circuit did not work in order to recover the points.

This implementation worked well. First of all, having a difficult laboratory project and giving students ample warning in class encouraged students to show up on time. They know that the laboratory experiment will not be easy to finish within the allotted time, and the "punishment" for not being able to complete the experiment is to write a laboratory report. In EE3407, it is also not difficult to create minor differences in each student's laboratory assignment. For example, when assigning students to build an audio buzzer, a slightly different frequency is assigned to each student making all the resistor, capacitor and inductor values slightly different. This makes plagiarism impossible.

Students who complete the laboratory project are proud of their accomplishments. Students who do not complete the laboratory project in time or do not finish the second part are motivated to write the laboratory reports. Their reports benefit immensely from the three hours of tinkering that the students will have put into trying to get their respective circuits to work. From an educator's perspective, this not only saves time in grading laboratory reports, but more importantly, it ensures that our efforts are largely devoted to those students who need the most help. Students who are unable to complete the technical aspects of their laboratory experiments are usually those who also need help with their writing. Thus, plagiarism is no longer the primary concern.

Students' opinions of the laboratory sessions in end-of-semester anonymous feedback indicate that they like the system, and their comments also reflect that the laboratory sessions are challenging. What is significant is that despite the difficult and time-consuming laboratory sessions, not a single complaint about the time constraints or difficulty was recorded in the anonymous feedback, even after doing this with six batches of students.

This system has worked well in eliminating the risk of students plagiarising previous semesters' or their peers' laboratory reports. It has also worked well in encouraging students to be well-prepared for the laboratory sessions and to turn up on time. More importantly, it ensures that students who are struggling with the technical aspects of their laboratory projects get help not only in the technical aspects of their projects, but also in their writing.

While it is not practical in all university laboratory classes to have individualised laboratory projects as was done in EE3407, it is always possible to have challenging laboratory sessions set at an appropriate difficulty level that releases the brightest students from the requirement of writing a formal laboratory report. Shocking as 'no laboratory reports required' may sound, the seemingly positive correlation between writing skills and laboratory skills is being leveraged here. The only drawback of this approach to laboratory teaching is that some of the most technically competent students may be non-native English speakers and may still benefit from having graded laboratory reports. It is suggested that a study be conducted in the hard sciences to quantify the correlation between academic achievement (grades) with writing skills, would allow the drawbacks and/or advantages of the teaching approach outlined here to be understood fully. ■

Enhancing Pharmacy Students' Understanding of the Principles of Recombinant DNA and Protein Technology

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The Pharmacy curriculum is constantly being reviewed and revised to ensure that students are equipped with the most up-to-date knowledge and skills when they join the professional workforce. Due to major breakthroughs in biotechnological research in the past decade, medications for the treatment of illnesses and disease states can no longer be limited to small molecule-based chemical entities. In fact, the profession is currently embracing an ever-increasing number of protein- and nucleic acid-based biopharmaceuticals which have been approved or are on trial for use as alternative treatment modalities. To prepare Pharmacy students for this changing paradigm in disease treatment and management, they are required during their four-year course to take up the essential module PR3104 "Pharmaceutical Biotechnology" in Semester 2 of their second year. In the module, which comprises lectures, tutorials and practical laboratory classes, students gain knowledge of the physicochemical properties of commonly used biopharmaceuticals, the various biotechnological techniques used in the manufacturing of biopharmaceuticals and the principles which govern the mechanism of some common biotechnologically-derived diagnostic aids. However, students who had taken PR3104 in previous years had given feedback that they often found it hard to grasp the molecular biology-related concepts and techniques taught in the lectures.

An important aspect of teaching and learning science is laboratory work. A teaching-learning environment that involves the engagement of students in practical work enables them to learn science in an effective way (Berry, Gunstone, Loughran & Mulhall, 2001; Nakhleh, Polles & Malina, 2002; Wang & Coll, 2005). Indeed, conceptual learning of the principles of recombinant DNA and protein technology can be effectively achieved through hands-on experience in a laboratory.

In Academic Year (AY) 2009/2010, to increase students' understanding of these molecular biology-related concepts and techniques that were taught in the lectures, I introduced a demonstration cum hands-on session in the practical class. In this practical session, entitled "Cloning, Expression and Purification of a Flavoprotein", students were asked to conduct an experiment that involved the whole process of making a recombinant protein. This would include making a DNA construct of a tagged protein, followed by growing transformed *E. coli* bacteria to harvest and purify the recombinant protein. It should be noted that we divided the class of 126 students into 4 groups, and the groups were rotated around the practical schedule. As such, the practical class was conducted a total of four times, and each session had around 31 students.

As the experimental work to construct the DNA plasmid had to be performed weeks in advance of the practical session, we gave the students a 30-minute briefing at the beginning of the practical to highlight the key steps which had been taken to obtain the correct DNA plasmid. These steps included designing primers for the gene of interest, the choice of vector to be used for gene insertion and how to read a vector map, the polymerase chain reaction (PCR) conducted to clone the gene of interest carrying the desired restriction sites, as well as the final ligation of the cloned DNA insert into a restricted vector plasmid. The briefing was followed by the demonstration cum hands-on practical session that lasted approximately two-and-a-half hours. Students were split into groups of 10 to 12, where each group was guided through the practical session by a demonstrator. The demonstrator team comprised a lab technologist, a graduate student as teaching assistant, and myself. My team members had already been given a prior briefing and training session by me to ensure that all three of us provided the same level of scientific guidance to the students. To reinforce the theories of gene cloning discussed during the briefing, students were asked to digest the DNA plasmid with restriction enzymes, followed by the separation of the digested contents by agarose gel electrophoresis and the final illumination of the nucleic acids using ultraviolet excitation. The visualisation of the cut DNA insert on the agarose gel would allow for easier understanding of the need for restriction sites to be included in the cloned gene for insertion into the vector. During the practical, students were also instructed to purify the recombinant protein produced by transformed *E. coli* bacterial culture through the use of a series of phosphate buffers with varying eluting salt concentrations. To arouse students' interest and instill a stronger visual understanding of the process, a yellow flavoprotein (due to the presence of a prosthetic FAD cofactor bound to the protein) instead of a colourless protein was chosen to be produced in the experiment.

At the end of the practical session, as a measure of students' learning outcomes, each student had to prepare a lab report to showcase their understanding of the common molecular biology-related concepts and techniques covered in PR3104. The content to be included in the lab report comprised three parts. For Part (A) "Design and making of pET41HisAIF(121) DNA construct", the concepts and principles had been discussed in lectures, tutorials, as well as during the briefing at the start of the practical. Students were required to summarise their knowledge by applying the known approaches and techniques in a written format on the lab report. For Part (B) "Digestion of DNA plasmid with restriction enzymes", students were asked to interpret the results of an illuminated agarose gel image showing DNA bands of digested and undigested plasmids (see Figure 1).

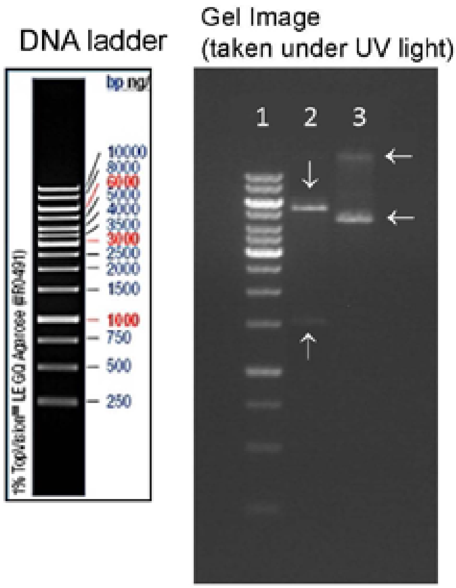

Figure 1. An illuminated agarose gel image. The lanes labeled 1to 3 on the gel image refer to: the DNA ladder (Lane 1), digested plasmids (Lane 2) and undigested plasmids (Lane 3).

The objective of Part (B) in the lab report was to stimulate students to develop independent thinking skills based on the properties of DNA and the principles of DNA cloning, as well as encourage them to conduct self-directed learning through further reading up on textbooks and other references. For Part (C) "Bacterial culture, bacterial pellet harvesting and protein isolation/purification", students had to discuss the rationale and principle of protein purification of the Histidine-tagged (His-tagged) recombinant protein. The principle of His-tagged protein purification had not been covered in the lectures, but it could be considered a form of affinity column chromatographic protein purification, a topic that had been covered in the lecture. The objective of Part (C) of the lab report was to encourage students to reveal the principle underlying His-tagged

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protein purification and to draw inferences to a practical and common example of affinity column chromatographic protein purification.

The students' lab reports had been read by the instructors and any clarifications which were required in relation to misinterpreted molecular biology and protein purification concepts had been penned in the reports. These reports were returned to the students before their exams. From the content of the reports, it could be concluded that students generally understood the various cloning steps in molecular biology. A common misinterpretation was the differential use of the two origins of replication within the plasmid vector, which had been clarified in the feedback comments to the students. For Part (B) of the lab report, students did well in correctly interpreting the results on the illuminated agarose gel image. Similarly, for Part (C) of the report, students were generally able to understand the principles of affinity column chromatographic protein purification and the crucial role buffers of different salt concentrations could play in the entire protein purification process. The lab reports also included positive remarks to the students; these served as a form of encouragement as well as a vote of confidence to the students that their self-directed learning had resulted in positive outcomes.

When we returned the marked lab reports to the students, a written survey was conducted to ascertain their responses and attitudes after experiencing this approach. 90% of the 109 students who responded found the demonstration cum hands-on practical session useful in allowing them to gain a better understanding of the concepts of molecular cloning and protein purification. Students had also voted which part(s) of the practical session they found helpful in enhancing their understanding of concepts; the findings were tabulated in Table 1.

Table 1. Parts of the practical session which students found helpful in enhancing their understanding of concepts

Parts of the Practical Session	No. of Votes by Students*
The briefing	3
The entire hands-on experience	15
The handouts/notes	5
The vector map	12
Primer design	17
6 x Histidine tag	14
The yellow protein	6
Use of different buffers	14
Chromatographic elution of protein	13
Laboratory report	8
All (the whole practical session + laboratory report)	15

*The votes indicate which parts of the lab session they found useful in helping them gain a better understanding of the concepts.

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In summary, the demonstration cum hands-on practical session effectively complemented the in-class lectures by allowing students to comprehend with greater clarity the concepts which govern molecular biology. Practical laboratory work is an active learning activity. By adopting a hands-on approach to go through the entire process of making a recombinant protein, the practical session not only enhanced students' understanding of recombinant DNA and protein technology, but also exposed them to the real-life practical applications of biotechnology.

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The Centre for Development of Teaching and Learning (CDTL) engages in a wide range of activities to promote good teaching and learning at the National University of Singapore, including professional development, teaching and learning support, research on educational issues, and instructional design and development.

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