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# Development and Implementation of a Flipped-Classroom Delivery in Engineering Computing and Analysis for First Year Engineering Students

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## Abstract

University of Wollongong recently undertook a major restructure of its academic and professional units, after the appointment of a new Vice Chancellor in 2012. As a result, the previous 11 faculties have been merged and rationalised into five new faculties. The Faculty of Engineering and the Faculty of Informatics merged to become the Faculty of Engineering and Information Sciences (EIS), consisting of six schools representing a total of 13 disciplines. Following the restructuring, EIS made the decision to develop a new common first year curriculum for all engineering undergraduate programs, spanning nine disciplines, they being; civil, mining, environmental, electrical, computer, telecommunications, mechanical, materials and mechatronic engineering. The process of developing the new first year subjects was undertaken in 2014 by a Task and Finish (T&F) group aiming for full implementation at the commencement of 2015. Through consultation with key stakeholders from each discipline area, as well as teaching teams from existing first year programs, five new engineering subjects were to be created, to coexist with the unaltered physics and mathematics subjects. The T&F group met regularly over the course of 2014, where they initially tasked with identifying the key mastery skills that all engineering students should have developed by the end of their first year of full time study. These skills were then grouped into themes, leading to the creation of the five new subjects. The final role of the T&F group was to report back to the Heads of School who would then assign key personnel to develop the curriculum content for each new subject. This paper will focus on the development of one of those newly created subjects, ENGG105 Engineering Computing and Analysis, which adopted the flipped-classroom approach to deliver the subject content.



## Keywords

flipped-classroom, students, implementation, development, first, year, engineering, computing, delivery, analysis

## Disciplines

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# Development and Implementation of a Flipped-Classroom Delivery in Engineering Computing and Analysis for First Year Engineering Students

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## Introduction

The University of Wollongong recently undertook a major restructure of its academic and professional units, after the appointment of a new Vice Chancellor in 2012. As a result, the previous 11 faculties have been merged and rationalised into five new faculties. The Faculty of Engineering and the Faculty of Informatics merged to become the Faculty of Engineering and Information Sciences (EIS), consisting of six schools representing a total of 13 disciplines. Following the restructuring, EIS made the decision to develop a new common first year curriculum for all engineering undergraduate programs, spanning nine disciplines, they being; civil, mining, environmental, electrical, computer, telecommunications, mechanical, materials and mechatronic engineering.

The process of developing the new first year subjects was undertaken in 2014 by a Task and Finish (T&F) group aiming for full implementation at the commencement of 2015. Through consultation with key stakeholders from each discipline area, as well as teaching teams from existing first year programs, five new engineering subjects were to be created, to coexist with the unaltered physics and mathematics subjects. The T&F group met regularly over the course of 2014, where they initially tasked with identifying the key mastery skills that all engineering students should have developed by the end of their first year of full time study. These skills were then grouped into themes, leading to the creation of the five new subjects. The final role of the T&F group was to report back to the Heads of School who would then assign key personnel to develop the curriculum content for each new subject.

This paper will focus on the development of one of those newly created subjects, ENGG105 Engineering Computing and Analysis, which adopted the flipped-classroom approach to deliver the subject content.

## The Flipped-Classroom

The ‘traditional’ lecture as a teaching method is still widely accepted as the most efficient way to deliver course content to a large audience in a relatively short period of time. However, it is also acknowledged that this largely passive form of instruction (Richardson, 2008; Toto and Nguyen, 2009) can lead to a lack of engagement by students and ultimately a drop in lecture attendance, which is becoming more of a common issue across the tertiary sector. Another related issue to contend with is that if students do not fully understand a concept taught during the lecture, they will then find it hard to complete their assessment tasks unless they are able and willing to seek assistance from the instructor.

The flipped classroom, when implemented successfully, can address this passiveness by first providing a portion of what would normally be covered in a ‘traditional’ lecture for students to access asynchronously prior to attending class. It should also be acknowledged that when introducing the flipped classroom format for the first time, students can be resistant to having to do pre-lecture preparation (Freeman Herreid and Schiller, 2013).

The most common form of pre-lecture content is video; whether that be pre-recorded lecture content, videos showing how to solve problems or case-studies or narrated PowerPoint presentations (Lage et al., 2000; Toto and Nguyen, 2009; Fulton, 2012; Larson and Yamamoto, 2013), however, readings are also commonly used (Lage et al., 2000; Moravec et al., 2010). The videos can be created by the course staff or accessed from online sources, such as YouTube. Previous studies have reported that students perceived the video portion of the pre-lecture content a benefit to their learning (Kadry and El hami, 2014). A key benefit of having them available before class is that students can watch videos as few or as many times as they would like to sufficiently understand the material (Fulton, 2012). By engaging with this material, the synchronous lecture that follows can be redesigned to provide an active deep learning environment that students are pre-prepared to engage in, exploring new knowledge (Hughes, 2012). This also provides another opportunity for students still with misconceptions to seek clarifications during the synchronous lecture.

The general consensus is that if the flipped-classroom is to work well, an incentive also needs to be attached to the pre-lecture learning, otherwise students will not make use of them adequately. In previous studies this has been successfully achieved by requiring the completion of a short pre-lecture quiz (Toto and Nguyen, 2009; Enfield, 2013; Jungic et al., 2015) or short pre-lecture assignment (Moravec et al., 2010). Enfield (2013) also noted that there was a drop in engagement in a subject taught later in the semester when there were no further video quizzes. It is suggested by Frydenberg (2013) that these quizzes be summative as an added motivation, as there is a direct impact on a student's final grade.

For the synchronous lecture, an active learning environment can be established, using various combinations of discussions, problem solving exercises (Toto and Nguyen, 2009) or experiments and demonstrations (Lage et al., 2000; Enfield, 2013). Micro-lectures of no more than 3 minutes have been used to bring order back to the lecture environment if and when required (McLaughlin et al., 2014). However, careful consideration is needed for structuring the lecture, with Toto and Nguyen (2009) noting that while students like the active learning occurring in the lecture, if those activities are not well planned, there can be periods of time where they are sitting waiting for things to be handed out. This could be overcome by having additional staff in the lecture to aid in efficient distribution of material.

## Rationale for Adopting the Flipped-Classroom Approach

The first and second authors were members of the team formed to develop the subject curriculum. In the initial planning meetings of this team, a broader initiative called the Curriculum Transformation Project (CTP) at UOW was also discussed. The CTP is a plan for UOW to enhance its national and international reputation in teaching and learning, with one of the key targets being to establish the next generation of innovative curriculum design. The team decided that this would be the perfect opportunity to develop a delivery format radically different to that previously seen in Engineering at UOW, whilst ensuring that the student learning experience includes elements of the three major themes identified by the CTP; intellectually challenging, research/inquiry based and technologically enriched.

The purpose of establishing the flipped-classroom approach for the computing subject was primarily to create an active learning environment, where students could take ownership of their learning. This would require students to undertake a much more active role than they would otherwise have encountered, or would have been prepared to engage in, with the 'standard' didactic lecture approach. For computer programming, students learn more effectively by doing, not by listening to an academic talk to them in a lecture setting. By flipping the classroom, some of the emphasis is placed back onto the students to prepare for the weekly lecture and computer laboratories ahead of time, rather than turning up for classes with little or no preparation, which is increasingly prevalent at the tertiary education level.

This subject would also expose the students to the active learning concept for the first time in their university life. Active learning is something which all students need to embrace, to achieve the desired learning outcomes in the subject, as well as for their lifelong learning once they reach the workforce. There are a number of stakeholders who will benefit from the successful implementation of this flipped-classroom initiative, including current and future students of the subject, as well as teaching staff and subject coordinators of other engineering subjects who can adapt their deliveries and assessments in similar ways, when appropriate.

## Development of Subject Curriculum

Many suggestions were made as to the type of programming that should form the basis of the subject, from VBA scripting in Microsoft Excel, Matlab and C/C++. Each of these options had a pre-existing place within the engineering disciplines, but the practicalities of delivering all three, to a sufficient level, was found to be unworkable. A compromise was finally agreed on that Matlab would be the tool of choice, providing a clean working environment, as well as exposing the students to the fundamentals of computer programming, which could be expanded upon in other programming languages later in their university studies. Additionally, to provide an engineering context to the programming, rectilinear and curvilinear particle dynamics concepts were also incorporated into the course structure.

Another early decision was to reduce the lecture to one hour from the standard two hours and to also have two hours of practical classes and two hours of workshop classes each week for students to actively engage in using the Matlab software. Weeks 1, 2, 6, 10, 11, 12 and 13 covered Matlab topics alone while weeks 3, 4, 5, 7, 8 and 9 also included dynamics content.

An integral component of the flipped-classroom is to provide a range of pre-lecture material, however, to do this successfully, an important question needs to be asked, "How do we motivate the students to engage with this pre-lecture content?". It should not be limited to just uploading the content online and the students performing the work, especially for first year students, most of whom have probably been reliant on their high school teachers for the last six years, telling them what to do and when to do it. University students also very quickly learn to become assessment-driven and when resources are made available, it is generally only those students with high levels of self-efficacy who will engage with this material, regardless of direct or indirect assessment implications. These students are generally not the ones who need to access the material, as in most cases they will succeed regardless.

The pre-lecture material predominantly consisted of videos supplied from MathWorks, the creator of the Matlab software programme and dynamics videos (lecture and tutorial problems) created by author one for the appropriate weeks. To encourage student participation, summative assessment was attributed to these pre-lecture activities. To ensure weekly pre-lecture videos were reviewed, twelve weekly summative LMS quizzes were developed to encourage student engagement and to allow a more active role in the lecture each week. Each of these pre-lecture quizzes (PLQ) was assigned a maximum possible mark of 1% and the best 10 of the 12 quiz results counted towards the final grade and there was no restriction as to the number of attempts that could be made for each quiz. The quizzes were predominantly multiple-choice type, with the Matlab questions being comprehension style, based on the videos. For dynamics there was a mix of calculation style questions and comprehension. The comprehension questions were used as an added incentive for watching the videos.

As stated previously, the students were exposed to four hours of practical and workshop computing in total each week where they completed exercises from the prescribed textbook and also undertook a range of problem-solving programming activities. Both of these classes had an assessment component each week worth 1% and again the best 10 of 12 of each counted towards the final grade. One subject coordinator was assigned with the responsibility of monitoring participation rates and students not participating were contacted weekly to remind them of the summative nature of the assessments. The students also completed a 'traditional' style group assignment, where they were provided with a 'realistic' engineering data set that they had to analyse using the programming skills and kinematics concepts they learnt during the subject. A final exam constituted the remainder of the assessment requirements. Figure 1 illustrates the key engagement activities students needed to participate in on a weekly basis to succeed in the subject.

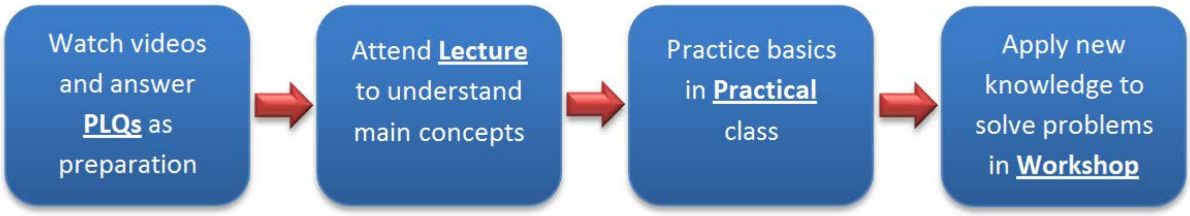


**Figure 1** Structure of weekly activities

## Experiences During the Semester

Initial enrolments saw numbers close to 460 students, however, after the withdrawal of students throughout the semester, the final figures closed at 412 students and it will be these 412 students that the key indicators presented in the next section, are based upon.

Early in the semester there were anecdotal comments from a cohort of students that the calculus component of the subject (mainly in the kinematics sections) was too difficult. This was considered to be due to the fact that these students had studied a non-calculus level of mathematics in high school and therefore they were enrolled in the enabling mathematics subject. However, calculus was not covered in that subject until later in the semester due to the way topics were scheduled. Additional resources were then made available on the learning management systems (LMS) to cater to these students to aid in their understanding, while they waited to cover this vital content in their enabling mathematics subject.

Additionally, owing to the unforgiving nature of learning a programming language for the first time, some students requested additional support and so students were also offered completely voluntary ‘Help’ sessions. Initially these were set up through Adobe Connect to generate a virtual classroom where outputs on computer screens could be shared with all attendees. It was soon found that attendance at these was low and on asking, it was discovered that students actually preferred face-to-face interaction. A face-to-face version of the ‘Help’ sessions was then trialled; however, this also saw attendances dwindle in a very short time, even though students initially requested this type of assistance.

Some students queried why all the constant 1% assessment was required. There were a number of reasons given as why this was seen as the ‘most appropriate option, they being;

- if no weighting was given to the pre-lecture quizzes, there would have been substantially less engagement and then the lecture would not make sense to a large proportion of the student cohort,
- if Practical and Workshop assignments were given no weighting, that 20% would have to be applied somewhere else, most likely a mid-semester exam,
- generally a 1% weighting is enough incentive to encourage students to try but at the same time is not so critical that a bad result will impact significantly on final marks, and
- consistent practice is crucial to mastering the skill of programming, and the continuous assessment encourages that.

## Key Indicators

Of the 412 students enrolled in the subject, it was found that for the cohort of students who did not have the requisite knowledge of calculus, vital to the dynamics component of the course, their average final mark was 61.5% (n = 32, SD = 17.8) while the remaining students had an average final mark of 67.1% (n = 380, SD = 17.0). This implied that although their average mark was lower than the students with prior knowledge of calculus, the initial concerns by both students and the teaching staff had been adequately addressed either via the additional resources and assistance provided or through learning the content in their mathematics subject.

The LMS used at UOW is Moodle and student engagement was obtained from the LMS by extracting data from a combination of the reporting logs, activity reports and site participation analytic reports. The first activity each week was the engagement with pre-lecture content and the associated pre-lecture quiz. The PLQ analytics are presented in Figure 2, showing the average mark achieved in each PLQ (based only on the students who attempted the quizzes) and the completion rate of each PLQ. Assessment 2, 3, 4, 6, 7 and 8 consisted of 15 Matlab questions and 5 dynamics questions, while all other quizzes consisted of 20 Matlab questions. It can be observed that the combined mark for the PLQs sits in the range between 15 and 18 out of 20 for the first 11 quizzes, then the last quiz average drops off, most likely due to students already satisfied with the best 10 of 12 quiz marks being counted towards assessment. It can also be seen that there is a high completion rate for each of the quizzes, which is encouraging for such a large class. Of the 412 students who completed the subject, 86% successfully completed 10 or more PLQs. The numbering of the PLQs refers to the week of the assessment. Figure 3 drills down further to show the total number of attempts at each of the PLQs (note that PLQ3a, PLQ 4a refer to the Matlab PLQ components and PLQ3b, PLQ4b refer to the dynamics PLQ components, and so on).

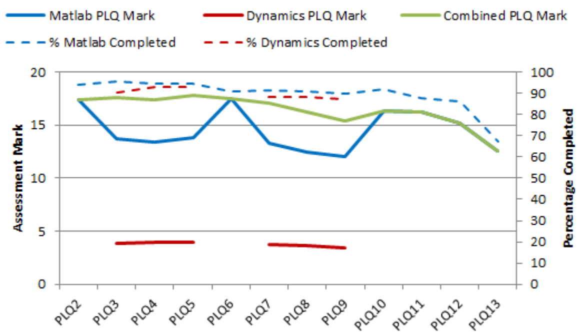


**Figure 2** Results for all pre-lecture quizzes

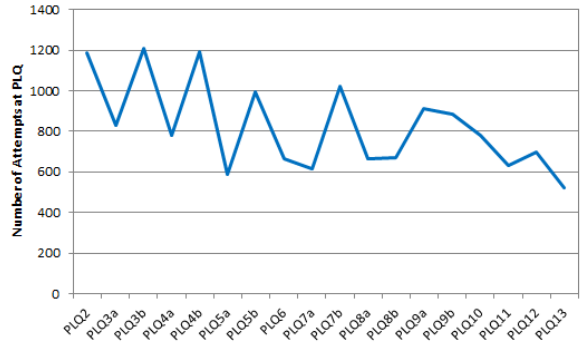


**Figure 3** Student engagement with the pre-lecture quizzes

The results from the 1% Practical assignments and Workshop assignments (WSA) were analysed to determine the uptake throughout the session. Figure 4 shows the average marks obtained for each Practical and WSA, but only for the students who actually attempted each assessment. The graph also shows the percentage completion rate for each of the assessments. There are a number of key points to take from this graph. Firstly, there is a downward trend in assessment marks through to the fifth assessment, which corresponds to the mid-semester break. For the first assessment, students start off keen at the beginning of semester, but as workloads increase and the content becomes more complex, marks can start to suffer. It could be that during the mid-semester break, students realised they needed to start focussing more to succeed in the subject or perhaps students also started realising that if they got the help of others, they could score higher, as well. It was noted by numerous lab tutors that the latter was quite common. It is also encouraging to see that up to the tenth assessment approximately 90% of students were completing the assessments. There was a noticeable drop-off for completion of the last two assessments, which can be put down to the best 10 of 12 assessments counting towards grades. Of the 412 students who completed the subject, 88% completed 10 or more Practicals and 84% completed 10 or more WSAs.

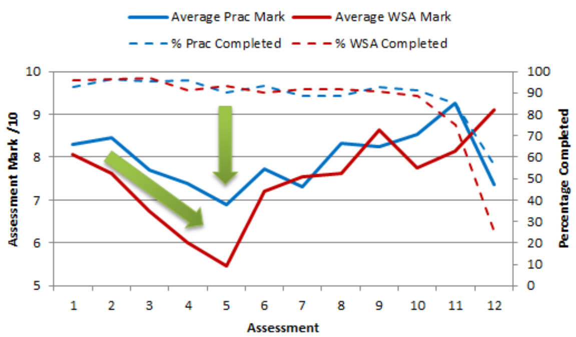


**Figure 4** Results of Practical and Workshop assignments

Some additional measures taken from the LMS are presented in Figure 5 and Figure 6. Figure 5 shows the overall student activity for all weeks of the semester. The initial flurry of activity can be seen in the early weeks of the semester, with a dramatic drop in the break week before building again for the second half of the semester. There is also another minor rise leading into the final exam, held in the first week of exams. Figure 6 drills down further to show the overall engagement in the key components of the flipped classroom structure. It should be pointed out that although the forum activity has over 30,000 hits, the majority is viewing of posts, but the actual breakdown could not be extracted from the LMS. Students had set up a first year engineering Facebook page where most of their communications took place, away from the eyes of the teaching staff. It is reassuring that there were over 14,000 views of the dynamics videos created by author one, indicating that these are valued. One metric that could not be accurately extracted from the LMS logs was views of the Matlab videos needed for the PLQs, due to the way the weblinks were added to the LMS. An estimation of the number of Matlab video views was made based on the number of hits to the dynamics PLQs compared to the number of views of the dynamics video problems.

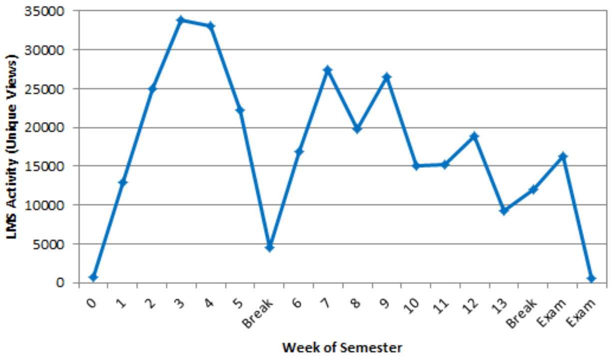


**Figure 5** Overall LMS activity by week of semester

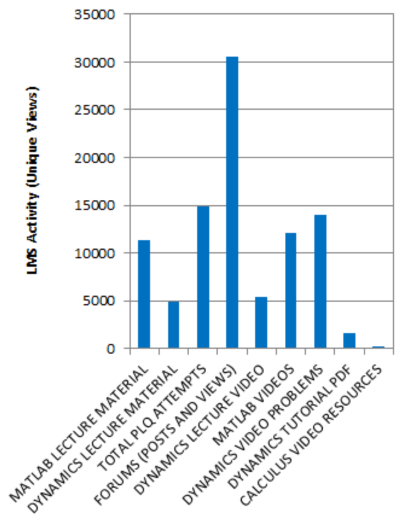


**Figure 6** LMS activity for key components of the flipped classroom

## Discussion and Reflections

It should be mentioned that the quality of the data obtained can only be as good as the reporting systems within the LMS being used. Specifically, the data reports the number of “hits”, however, it is generally recognised that this does not necessarily translate to number of “uses”. This can result in a slight distortion of the results which are presented.

The weekly 1% assessment in the Practicals and Workshops were the most vocally disliked component of the assessment mix because students felt they were rushing to complete the tasks rather than fully appreciating what they were trying to achieve. This will be a major focus of a scheduled review of the subject before 2016, with one possibility being to incorporate some formative assessment to adjust the balance.

The issue of whether students had the correct level of mathematics coming into the subject has partially been addressed, however, there will be a more structured selection of resources made available and even the possibility of reordering some of the subject content to cover calculus later in semester to better align with the enabling mathematics subject.

The time commitment outlaid by the teaching staff and teaching assistants has been substantial, but each successive year should involve more of a maintenance roll. This large time commitment is the major factor in academic staff being generally reluctant to drastically change the format of subjects, when most are already time-poor, spreading their time across teaching and research commitments. The emphasis has to be placed on the long term benefits if the flipped classroom approach is to succeed.

The teaching staff were satisfied with the overall delivery of the first implementation of the Engineering Computing and Analysis subject using the flipped classroom format. However, there are a number of matters which will need to be reviewed before the next implementation, based on student feedback and observations by the teaching staff. In general, the pre-lecture activities ran smoothly and the uptake by students was high, but there will need to be ongoing maintenance to the PLQs as well as supplementing some of the video content. The synchronous lecture will need close attention to ensure that the right mix of active learning activities can be deployed. Having a one hour lecture makes it extremely difficult to cover everything necessary, especially in the weeks when the Matlab and dynamics content is shared. It may be worth considering returning to a two-hour lecture to allow more time without increasing the content. The Practical classes had a mixed reaction from students. Anecdotally, some liked the structure where they followed exercises from the text to grasp the fundamentals but others did not like this. Similarly, in the Workshops, there were students who enjoyed the more open-ended problems where they got to code Matlab and experiment for themselves and then there were others who just wanted to know the 'answer'. The teaching staff also refrained from releasing the 'solutions' to the Workshop problems, particularly because there is no one correct answer when it comes to programming.

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