34th Australasian Association for Engineering Education Conference
3 - 6 December 2023 – Gold Coast, QLD

A blended approach to teaching statistics in a large second-year engineering mathematics course

Kevin Jia
University of Auckland
Corresponding Author Email: k.jia@auckland.ac.nz

ABSTRACT

CONTEXT

This paper presents work done over the last five years re-developing the statistics topic in the second-year engineering mathematics course at the University of Auckland with a blended approach to balance the delivery of key theoretical concepts and discussion of applied examples, to classes of 900+ students.

However, student resistance to learning statistics is well-documented internationally (Batson, 2018), and students at the University of Auckland are no exception. In New Zealand, students' background exposure to statistics is multi-modal, given there are three high school qualifications systems in use by New Zealand schools (NCEA, Cambridge A-Levels and the International Baccalaureate), and where Statistics is a separate subject to Mathematics at Year 13 under NCEA. This lack of engagement is exemplified by around 10% students leaving this section unattempted in the final exam.

PURPOSE

A blended delivery of the topic gives students ample opportunity to engage and understand the underlying statistical theory, so in-person contact time can be directed towards discussion and reinforcement of the key ideas, and case studies involving the use of statistical software to conduct analysis. Around half of the theoretical material was delivered via traditional lectures, while the other half was delivered via recordings only, with each recording associated with an assessed online quiz.

These changes intend to give students more time flexibility to engage with the theoretical material at their own pace and present opportunities for reinforcement in class. Coursework assessment focuses on conducting simple analyses and writing very short reports to reinforce good habits for statistical analysis.

APPROACH

A review of the student engagement data on platforms such as Panopto Video and student achievement are provided, and qualitative feedback considered.

ACTUAL OR ANTICIPATED OUTCOMES

Most students engaged with the material, with around 60% of students consistently watching lecture recordings. Student understanding and satisfaction appeared to have improved in terms of exam marks, but that could be due to changes in lecturers and approaches. However, the COVID-19 pandemic meant that recent cohorts did not fully develop good study habits through high school and/or first-year University, and a proportion struggled to keep up with the blended learning.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The reinforcement opportunities afforded by a blended approach means that students can better engage with conceptual statistical material that is different to traditional mathematical methods. However, students need to be motivated appropriately to use a blended approach effectively, and the COVID-19 pandemic impacts mean that explicit expectation-setting is required. Wider investigations into reasons for Engineering-intending students choosing not to do Statistics at high school, where that is an option, is recommended, as that directly impacts the knowledge assumed by University courses.

KEYWORDS

Engineering statistics, blended learning, student engagement

Introduction

Engineering statistics is a compulsory topic in standard engineering mathematics courses in Australia and New Zealand, with most programmes dedicating between half to one semester on this topic. At the University of Auckland, engineering mathematics is taught by the Department of Engineering Science in service courses to all engineering students. The first-year course contains an introduction to probability; while statistical analyses is taught in the second- and third- year courses.

Probability and statistics topics have fearsome reputations in engineering mathematics courses in general because of the unfamiliar nature of the concepts and lack of time to treat them in detail. It also goes against students' expectation that engineering is fundamentally deterministic, so studying randomness is seen as superfluous (Wilson, 2002).

Within the course, a substantial proportion of students did not engage with the topic because it was perceived as too difficult to decipher and irrelevant to their careers, and is hence 'boring'. Constructive student feedback throughout the deliveries expressed a desire for both more explanation of the theoretical underpinnings of the analyses, and also for more examples to be done in class. The feedback can be partially explained by the diverse exposure and preparations that the students have in statistics, and the topics taught within statistics courses in secondary schools in New Zealand.

In terms of blended learning in engineering in general, Green et al. (2012) noted that students reported that they gained deeper understanding of course content by watching screencasts which was reflected in their course performance. Green recommended that screencasts can be used for first exposure to concepts, and that students are more likely to use screencasts if they can see these as enhancing their competence and performance. Dart (2020, 2022) examined the effectiveness of worked example videos for traditional engineering and business statistics respectively, and found that students primarily used these for exam revision, reflecting the assessment-driven nature of higher education.

Student Entry Backgrounds

In New Zealand, there are three secondary school qualifications offered by schools to students, which have different approaches and levels of preparation for statistics.

National Certificate of Educational Achievement (NCEA). This is the local qualifications systems operated by the New Zealand Qualifications Authority, taken by about 75% of students entering Engineering. It is a standards-based assessment system where each subject is divided into a set of Achievement Standards with a set number of credits (each credit representing approximately 10 hours of work), and students receive a grade of Not Achieved, Achieved, Merit, or Excellence depending on their level of performance.

Students complete Level 1 in Year 11, Level 2 in Year 12, and Level 3 in Year 13 for University Entrance. Standards are either internally assessed by schools (e.g. for research or experiment based topics), or externally assessed by NZQA in an end-of-year exam. Around 25-30 credits are available for each subject, from which schools generally select around 20 credits to teach. Most students study five subjects at Year 13 level. (New Zealand Qualifications Authority, 2023).

Cambridge Assessment International Examinations (CAIE), taken by about 17-20% of students entering Engineering. A small number of schools in New Zealand offer CAIE's IGCSE and A-Levels, which are equivalent to those offered in the United Kingdom. Almost all assessment is done through end-of-year examinations, which was appealing to some schools after the introduction of NCEA in 2002 (Walsh, 2000). Most students take 4 subjects at Advanced Subsidiary (AS) Level (Year 12), and 3 subjects at the full Advanced Level (A2, Year 13).

International Baccalaureate (IB). A few schools offer this qualification; these are mostly private schools. As of 2021, IB offers two mathematics syllabi: Analysis and Approaches and Applications and Interpretation (International Baccalaureate Organisation, 2019).

The merits, or otherwise, of these qualifications systems are beyond the scope of this paper.

For statistics, the CAIE and IB qualifications offer a ‘classical’ treatment in their Mathematics courses covering probability, hypothesis testing and confidence intervals. In contrast, NCEA Level 3 Mathematics treats Calculus and Statistics as effectively separate subjects, and only Calculus is required for entry into the BE(Hons) programme.

Further, the NCEA Statistics curriculum was re-written in 2013 to de-emphasise analytical methods to give a more applied, interpretation-focused view to the subject; statistical inference is done via the use of bootstrap confidence intervals and randomisation tests through iNZight software developed at the University of Auckland. There are currently three externally assessed standards, focusing respectively on evaluating statistical reports, probability, and probability distributions.

Statistical inference (e.g. comparison of averages and regressions) are now entirely internally assessed. These require students to write extensive reports that incorporate contextual knowledge for a Merit or Excellence grade; as such mathematically-minded students can and do find these internal assessments frustrating. At NCEA Level 2/Year 12, a good answer on comparing a side-by-side boxplot might require 150-200 words of highly structured answers (Hinchliffe and Priest, 2013). Anecdotally, students do not continue with Statistics into Level 3 as a result of this.

Figure 1 shows the completion rate of the Statistical Inference achievement standard (91582, and 90642 in 2012 and earlier) for ENGSCI 211 students who completed NCEA Level 3 in high school. There is a two-year lag in these results, i.e. most of the 2014 cohort completed NCEA Level 3 in 2012. Similar trends are observed for all other Statistics Level 3 standards. A significant decrease in the completion rate occurred in 2015, which coincided with the 2013 curriculum review in NCEA.

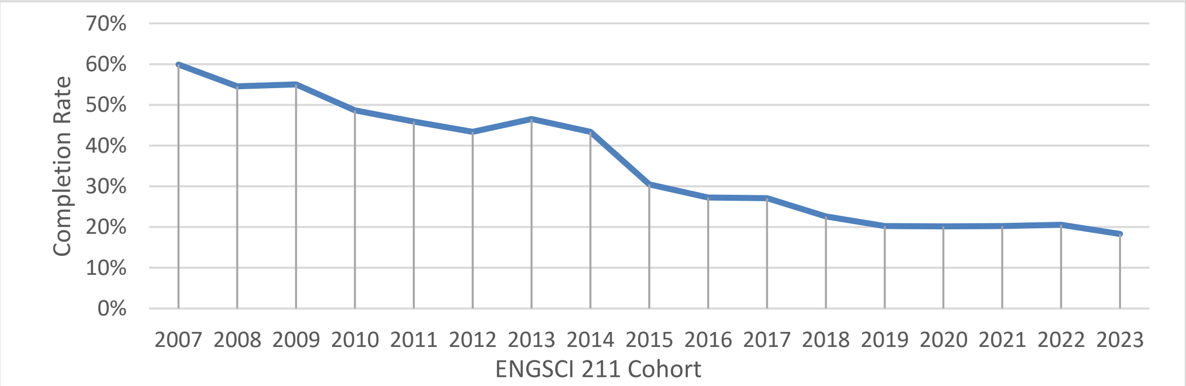

Figure 1: Completion Rate of the Statistical Inference Standard, for students in ENGSCI 211 who completed NCEA at high school.

The mix in student preparations (or lack thereof) means that no prior knowledge of statistics could be assumed when delivering this topic, even though in recent years around 35% of class members overall have some exposure to statistics through CAIE, IB or NCEA.

Pre-Existing Course Material and Feedback

Prior to 2017, the ENGSCI 211 lecture slides covered the following topics:

- Hypothesis testing
- One-sample and two-sample t-tests
- One-way analysis of variance for comparing average of 2+ groups
- Transformations for multiplicative effects

Linear and multiple regression was covered in third year in ENGSCI 311.

These notes were based on those developed for the second-year data analysis course in the Department of Statistics in the early-2000s. The assumptions behind each analysis, and how to check them, were discussed. The lecture slides showed significant amounts of mathematical derivations but this was never assessed in practice.

The author taught with these notes in 2016 and reflected that the mathematical derivations seemed out-of-place compared to the rest of the course. There was also no overarching theme to the analyses presented, as each analysis was delivered mostly independently of the others with separate workflows, so students cannot draw parallels between the procedures as easily.

Topic Design

The re-write of the topic coincided with a refresh of the course notes for second-year data analysis by the Department of Statistics. The review emphasised linear regression as an all-encompassing framework for simple statistical analysis and assumption checks, starting from estimating and comparing means, linear regression itself, multiple regression and analysis of variance. The course notes were stripped of most mathematical derivations, and there was more focus on understanding of model assumptions and interpretations.

On the Engineering side, the notes were also overdue for a refresh. Therefore, an adaptation of the notes was made and much of the mathematical derivations moved into extras-for-experts sections on Canvas only. In 2021, a further 1.5 lecture block on introduction to machine learning concepts was introduced to ensure that students are aware of the key concepts and ethical considerations in this popular field.

The removal of mathematical derivations from the core lecture slides created space for the regression topic to be covered, but not enough time to cover sufficient additional examples of analysis in class. Further reflection and previous student feedback highlighted that discussion of lecture slides was not a particularly engaging use of in-person lecture time.

As such, a blended approach was trialled in the second-year course from 2019 as part of the rewrite, in order to allow a proportion of the heavy conceptual content relating to the application of definitions and modelling assumptions to be discussed online so students can view (and re-view) these at their own pace, and which would otherwise be ‘boring’ in a lecture theatre environment. As the content is also English-language rich, this particularly benefits students for whom English is a second language. All flipped lecture recordings are made available from the first day of the topic, to give students maximum flexibility.

However, the topic was not entirely flipped. Moffet (2015) suggest that lecture material around 40-50% flipped is usually ideal as students learn best via a mix of teaching methods. For this course, the initial lectures on hypothesis testing and confidence intervals are given as in-person lectures to emphasise its importance and to allow for live class demonstrations to be done. However, the flipped recordings of these are available should students wish to learn at their own pace. Each recording was about 20-25 minutes long, and is accompanied by a Canvas Quiz worth approximately 0.5% to incentivise students to keep up with the pacing of the topic.

In the continuation of the topic in third year, flipped lectures are intentionally not used because of the myriad of design projects that the course must compete for time with.

After each block of flipped lectures, the in-person lectures contain a chalk-and-talk discussion and review of the topic to cement student understanding, allow for misconceptions to be clarified, and engagement from the audience in constructing a live summary of the topic. This is followed by pop quizzes where multichoice questions are used to give quieter students a chance to engage directly – coloured coursebook pages were used in earlier years, and Mentimeter was introduced in 2023 to allow for gamification, although licensing now make the use of this difficult. After this, around 1.5 hours of case studies per topic were discussed, where code examples and reports are constructed live, with student contribution, to highlight key points of understanding and demonstrate assessment expectations.

Past exam questions are also discussed when time permits, to further ensure students are left in no doubt as to how they might be assessed.

Assessment

The major coursework assessment for ENGSCI 211 is an assignment, where students complete three data analysis tasks: generally a *t*-test, a regression, and an one-way ANOVA. Students are expected to conduct the analysis like class examples, and write formulaic reports that emphasise:

- Exploratory analysis, i.e. looking at the data for its key features/trends
- The assumptions in the model, and whether they are satisfied (or not)
- The equation fitted to the data
- Quantifying confidence intervals for effects and predictions, as point estimates do not give any indication of the uncertainty in the estimates which is important for understanding what is going on.

Students are not expected to speculate on why the data displays certain trends; however, the course does emphasise how subject-matter-experts are expected to be able to give explanations for trends in the data, and that their other courses and work experiences will be what allows them to give informed explanations.

Although reports following such a fixed template are not done in real life, a strongly templated report ensures that students fall into good habits when interpreting statistical analyses in general, e.g. reporting confidence intervals instead of point estimates, and ensuring that the direction of effect is correct (Forster et al., 2005). It also ensures that students for whom English is a second language can also confidently complete the assignment.

In the written test and exam, the above points are also examined through requiring students to interpret already-completed analyses and R output, along with questions that test student understanding of the concepts of statistical inference and assumptions (e.g. *p*-values, confidence intervals, regression assumptions).

Software Choice

As the focus of the topic is on applied statistics, statistical software is needed to complete the assessment tasks. R and RStudio was retained as the software and graphical user interface, as this is already used in the course, and is free and open-source. Indeed, R was created at the University of Auckland. The Statistics Department also developed a package, s20x, which contains useful functions for producing diagnostic plots.

Practically, R and RStudio is easy to run out-of-the-box and has a fairly straightforward package management system that is self-contained. This reduces cognitive loading for most students to allow focus on statistical concepts. Although Python is well-used in industry and software development, it is also more difficult to install for students with less familiarity with the command line, and its statistical functions are buried deeply in packages like statsmodels. Excel cannot easily produce diagnostic plots, and specialised statistical software (e.g. Minitab, Stata, SAS) all have steep learning curves.

The use of R was limited to scripting in the console, rather than as a programming language. There is insufficient time for R’s tidyverse or data visualisation in ggplot2 to be taught.

Revision Sheet

Because this is a concept-heavy topic, a revision sheet of bullet points of big ideas that students are expected to understand is issued at the start of the topic on Canvas, to again reinforce to student the level of understanding required to do well in the section.

Delivery during the COVID-19 Pandemic

During the COVID-19 pandemic, the pre-made flipped lecture recordings meant that the topic easily transitioned into fully online delivery. Asynchronous delivery was encouraged by the University administration to give flexibility to students.

However, to ensure keen students remained engaged, a live lectorial on YouTube was delivered once a week for the Data Analysis topic. Students were given two exam-style questions in advance of each lectorial, and the questions were discussed live during the lectorial with opportunities for student interaction via Sli.do Q&A and polls. Zoom was not used because the Zoom chat is a distraction, and Sli.do allowed for more control over student posts.

Assessment during the COVID-19 Pandemic

No changes were made to the assignment because students still needed to conduct simple analyses for themselves as a learning outcome.

University policy meant that the tests and exam for these courses were required to be open-book, online and non-invigilated between 2020-2022. This was 24 hours in 2020 Semester One, and 1-hour for tests and 3 hours for exams in other semesters. The following changes were made to tests/exams as a result:

- Removal of all questions requiring rote-learning. It was a course tradition to ask students to recall the definition of a p-value in ENGSCI 211. However, this was removed in favour of scenario interpretation questions to test deeper understanding of the definitions.
- In the 24-hour test and exam situations, a simple analysis in R was required. These were standard analyses with no complications, but gave students another opportunity to demonstrate their mastery of this learning outcome.
- Questions requiring explicit identification of analyses for a given situation was also introduced during online exams to test deeper understanding; as this was not in past exams, students did poorly in these questions.

With open-book online exams, academic integrity was a significant issue, with collaboration (both in-person and on Discord) and Chegg use rife. In the case of Chegg, the approach taken by most ‘experts’ were such that students using Chegg were easily identifiable. However, it was almost impossible to detect cases of collaboration between students, given that students could easily work together in a group in-person or online without invigilation.

Outcomes

Although this work started in 2019, there were only two proper deliveries of the blended topic in 2019 and 2023. In 2020, COVID-19 lockdowns led to a fully online delivery; in 2021 and 2022, although the blended delivery occurred at least in part, the tests and exams were online so the reliability of the engagement and student achievement data is questionable.

Student Engagement

With available data, student engagement can be measured in two ways:

- Panopto engagement: this provides a view of student participation rates with the flipped lecture material.
- Final exam marks: due to changes in lecturers and COVID disruptions, a comparative analysis between different semesters is not valid. However, it does provide some insight into student behaviour and engagement with the topic, relative to the other topics.

Given privacy and ethics considerations, only data in aggregate are reported in this section.

Panopto Engagement

In 2022, the Panopto video distribution platform was introduced to the University of Auckland. This allows for viewer data to be extracted from the platform. Table 1 gives a comparison between the view rates of two sets of recordings. Block 1 was the first flipped lecture at the start of the course, with the corresponding in-person review; and Block 4 was the final flipped lecture.

Table 1: Proportion of students viewing Panopto recordings

Year	Block 1 Flipped	Block 1 In-Person	Block 4 Flipped	Block 4 In-Person
2022	90%	(online only)	81%	74%
2023	82%	63%	77%	63%

As expected, there was decreasing engagement as the semester progresses. For in-person lectures, approximately 50-60% of the class attended in-person, and it is not possible to determine how many in-person attendees used the recordings as an additional review tool. In any case, it appears that a good proportion of students are using the resources available to them.

However, there is a marked decrease in engagement between the 2022 and 2023 cohorts. Anecdotally, this was reported by lecturers across all engineering departments. This is likely due to the 2023 Part II cohort being in Years 12 and 13 in 2020 and 2021 respectively, which were severely affected by COVID lockdowns and associated disruptions to study and examinations.

Similar to that observed by Dart (2022), lecture recording views peaked before assessment due dates.

Final Exam Marks

A direct comparative analysis between deliveries is likely invalid due to changes in lecturers, student abilities and entry backgrounds and requirements.

However, it was still of interest to determine a rate of disengagement with the topic. Table 2 reports this as measured by the proportion of students attaining fewer than 10 out of 25 marks in the topic in the final exam. The average exam mark for this section and overall are also reported.

Table 2: Disengagement Rate for Data Analysis, and average exam marks for selected years

Year	DA Disengagement Rate	Average DA Exam Mark (/25)	Average Overall Exam Mark (/100)
2016 (old notes)	6.7%	17.88	74.13
2017 (different lecturer)	23.8%	13.35	60.84
2019 (flipped lectures)	10.4%	15.94	60.26
2023	28.3%	13.22	63.66

The 2016 cohort was a particularly strong cohort, so it was not surprising that they had good results overall. In 2019, the introduction of flipped lectures appeared to improve student marks significantly relative to 2017; the 2018 data is unfortunately not available.

The impact of COVID on student preparation and work ethic is again shown in this data; although the overall exam average increased slightly relative to 2019, the data analysis average decreased and disengaged students increased substantially, suggesting that students in 2023 are ill-prepared for self-directed study despite years of being forced to do so. The 2023 exam was, for most students, their first in-person mathematics exam since NCEA Level 1 (Year 11) in 2019, so a lack of exam technique may also be evident.

Student Feedback and Responses

Student feedback is only discussed in general terms because separate student surveys with ethics approval for publication were not done.

Feedback for the blended approach was generally positive. Positive student evaluation comments generally focused on the flexibility and incentive to immediately review the material when the flipped lectures are used as intended, as is the ability to actively revisit parts of the recording as needed, which would not be possible in a live lecture. The case studies and past assessment questions discussed in class were also generally valued by these students.

However, there were a significant number of negative review comments, which provide opportunities for improvement. The general areas of feedback and changes made are listed below.

Additional Work

A good number of students felt that the flipped lecture recordings were unnecessary additional work that they were not motivated to do, and that course material should be confined to in-person lectures only, even though 40-50% of the class were exclusively watching recordings for both the flipped and in-person materials for most of the course.

Although there is an expectation that each course requires approximately 10 hours of work per week (inclusive of contact time, which for most non-design courses is about 4 hours per week), students routinely do not give courses sufficient time.

In response to this feedback, clearer expectations were communicated to students at the start of the topic and in the first lecture, indicating that the flipped lectures should be considered like pre-readings for a humanities course, and that the format of the course permits more discussion of examples for a heavily conceptual topic, and repeated exposure to concepts is needed for retention and better performance on the test and exam.

In 2023, an additional discussion on the psychology of learning was made after a disappointing Test 1 result (covering differential equations and calculus), to give students vocabulary on behaviouralism and constructivism, so they can better describe their learning methods and the consequences of such, and communicating staff goals in examining higher-level thinking.

Another contributing factor is student engagement in employment and/or extra-curricular activities, which are increasingly required to pay living costs in Auckland, and to be competitive in graduate recruitment respectively. This leaves students with less time to focus on University work and cannot be easily addressed at a course level.

Relevance of Statistics to Engineering

Another common issue raised was that statistics was not relevant for Engineering, and as such there is no reason to spend time on the topic. The topic was also seen as ‘boring’ by a good number of students. This was addressed by using more relevant examples in assignments and tests which either relate directly to engineering (e.g. electrical component testing, material failure), or are examples relevant to the everyday life of students (e.g. using McDonald’s menu prices to predict caloric content).

However, a contributing factor may be student pre-conceptions and poor experiences in high school aforementioned, compared to the relative ‘ease’ of formulating and solving equations.

Unclear Expectations

A small number of students reported that the expectations for assessment for this topic was unclear in 2022 and 2023, and that they were not able to complete assignments as a result. This is despite the volume of R case studies and exam examples discussed, and explicit mentions of how assignments have identical expectations.

This is a concerning comment because it shows a lack of engagement with course delivery. Some students deliberately choose to study by only reading the lecture notes and even encourage others to do so on social media (No_Earth_2560, 2023). It also appears, via Piazza discussions, that a small but significant number of students expect that exclusively doing past exam papers is sufficient study to obtain good grades.

Conclusions and Reflections

Blended learning can be used to teach heavily conceptual topics to some success, as it gives the majority of students more flexibility. The experiences here indicate that most students do engage with the course material, however the effects of blended learning on student learning is difficult to quantify fully, as other relevant factors also affect exam performance, such as familiarity with in-person exams and lecturer preferences.

Given the full range of background preparations and skills in English, having mostly predictable assessment tasks ensures all students can understand the topic and use it in their practice. The blended learning approach further provides flexibility.

Reflecting on student backgrounds and feedback, non-compulsory statistics at high school level, and poor experiences by students who do take it, is at least a contributing factor to student preconceptions about the topic here. Although communication of results is vital to both engineering and statistics, current curriculum expectations mean that students are likely voting with their feet away from statistics.

Blended learning requires a strong element of self-motivation, as it is very easy to fall behind on the lecture material. Much of the student feedback discussed earlier can be ultimately traced to a lack of understanding of how to learn effectively, and a lack of familiarity with study techniques due to COVID-19 lockdowns. Therefore, more work on explicitly communicating good study habits, starting in first year, is necessary to ensure that students learn how to learn effectively with less guidance from lecturers.

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Acknowledgements

The support of Cameron Walker, David Smith and James Curran in developing the course material is gratefully acknowledged.