

Learning and Teaching Initiatives Project Report Template

Project Title	Conceptual Learning with Interactive Applets
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Project Objectives

The original objectives of the project were:

1. To produce applets and/or supporting learning & teaching resources, for use in various subjects offered by the School of Mathematics and Statistics (and potentially elsewhere), using the software package GeoGebra;
2. To develop (with the assistance of Learning Environments) the necessary technical infrastructure to host GeoGebra-based interactive applets on the LMS, to incorporate them into online quizzes and other LMS-based activities, and to obtain analytics data from their use.

A further objective that arose as the project developed was

3. To stimulate professional development amongst teaching staff in the School of Mathematics and Statistics.

Project Outcomes Summary

The outcomes of the project were as follows.

Applets: 32 applets. These address a range of mathematical and statistical concepts, and are being used in at least 9 University of Melbourne subjects with exposure to over 5000 enrolments and over 2500 distinct students per year. Some applets are also being used at other institutions.

Supporting resources: A collection of supporting resources, including a *project website*, sample *online tutorials*, *instructors' notes*, examples showing the use of applets in *LMS quizzes*, and a *step-by-step guide* to embedding applets in the LMS.

Dissemination: Several academic papers have been written about the project (1 published to date, 2 more currently in preparation) and the work of the project was presented at various conferences and forums over the project duration.

Professional development: By engaging over 20 academic staff from the School of Mathematics and Statistics, the project helped foster discussion and collaboration about teaching and learning between staff and prompted staff to reflect on their teaching practice.

Pool of expertise: A range of academics and postgraduates from the School of Mathematics and Statistics were involved in applet design, development and use in teaching. This has produced a pool of expertise in the School which may be drawn upon in the future for similar endeavours.

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Detailed Project Outcomes

Applets. In total, the project produced 32 distinct applets¹. A screenshot of one applet is shown in Figure 1.

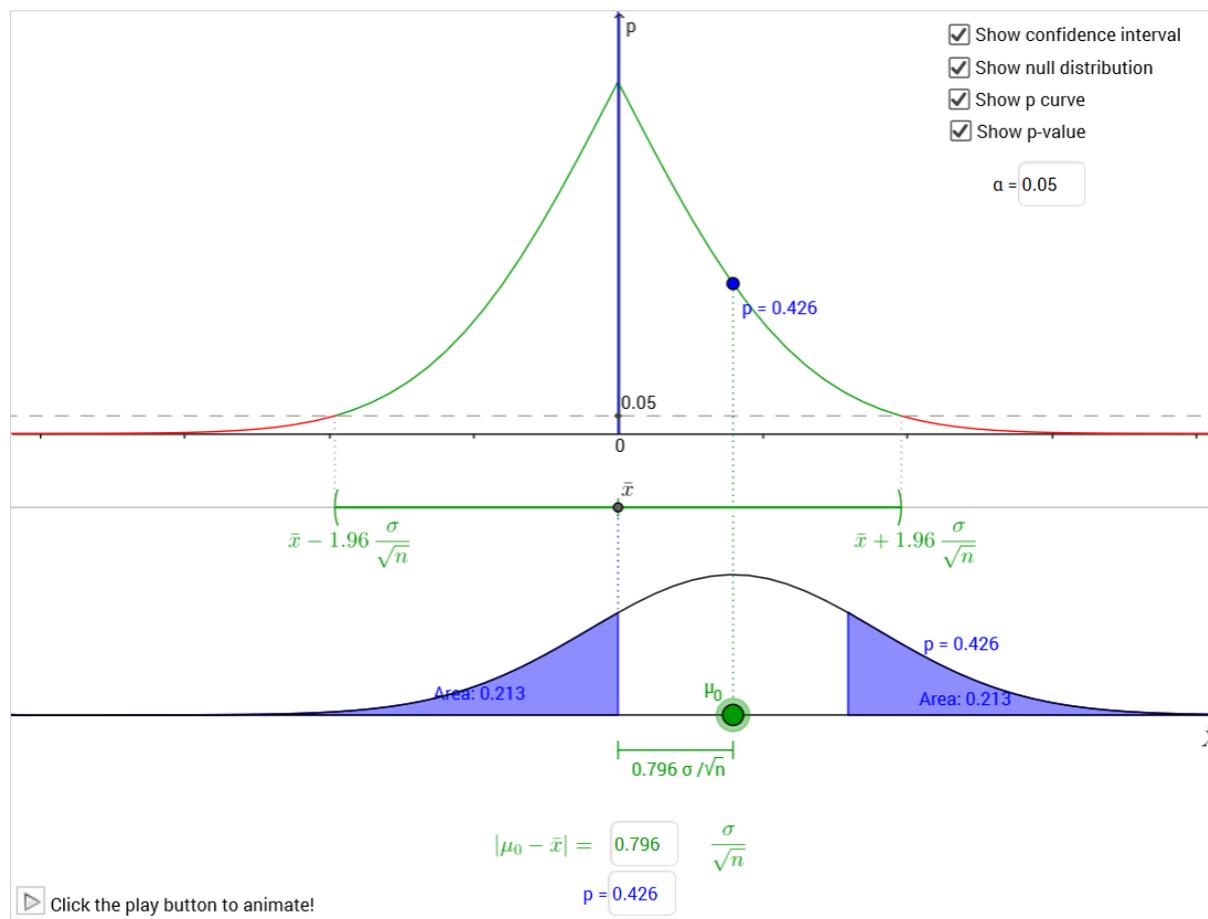


Figure 1: Screenshot of an applet illustrating the relationship between confidence intervals, p-values and hypothesis testing. Surrounding web browser window not shown.

The applets covered a range of mathematical and statistical concepts, and are being used in at least 8 subjects at the University of Melbourne. A summary of the applets, organised by subject area, is given in the table below.

Subject area & subjects	Applets
Calculus (first-year level) <i>MAST10005 Calculus 1</i> <i>(1300 students/year)</i> <i>MAST10006 Calculus 2</i> <i>(1800 students/year)</i>	Sequences and series Inverse of a function Parametric curves: Applet 1 and Applet 2 Continuity of a piecewise-defined function Exploring an ODE (Direction field and Euler’s method) Population model without harvesting Population model with harvesting Model of a spring with drag and forcing Model of an LRC circuit *

¹ This excludes several applets which are minor variations on other applets.

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Introductory statistics <i>MAST10010 Data Analysis 1</i> <i>(300 students/year)</i> <i>MAST10011 Experimental Design and Data Analysis</i> <i>(450 students/year)</i> <i>MAST90007 Statistics for Research Workers</i> <i>(100 students/year)</i>	Discrete and continuous probability distributions Normal approximation to the binomial distribution Confidence intervals, hypothesis testing and p-values Power of a hypothesis test Partitioning of variability in regression Partitioning of variability in ANOVA Normal probability plots Random variables
Intermediate probability & statistics <i>MAST20004 Probability</i> <i>(200 students/year)</i> <i>MAST20005 Statistics</i> <i>(200 students/year)</i>	QQ plots Distribution of order statistics Maximum likelihood estimators Central Limit Theorem and Law of Large Numbers Prisoners' Paradox *
Real analysis (second-year level) <i>MAST20026 Real Analysis</i> <i>(500 students/year)</i>	Formal ϵ-M definition of convergence of a sequence Formal ϵ-δ definition of convergence and continuity Differentiability Riemann sums and integral
Discrete mathematics <i>MAST10016 Mathematics for Biomedicine</i> <i>(450 students/year)</i>	Cobwebbing a difference equation Iterating a difference equation Discrete time population genetics model Cobwebbing, linear approximation and stability
Linear Algebra	Linear transformations of the plane and eigenvectors

Table 1: A list of applets produced by the project, grouped by subject area. The subjects in which the corresponding applets have been used, and typical enrolment, is also shown in the first column.

* These applets have not been published publicly at time of writing so links are not yet available.

The applets were developed using the open-source GeoGebra software package (www.geogebra.org). All but two of these applets were developed from scratch by the project; the other two² were derived from existing freely available GeoGebra resources. Six of the applets were originally developed in the pilot phase of the project (prior to LTI funding) and were refined during the LTI phase; the remaining applets were developed entirely as part of the LTI project. The applets were designed by the project team in collaboration with teaching staff from the relevant subject(s), and generally targeted key learning & teaching needs in the subject(s). They were tailored to the particular teaching & learning context of the relevant subject(s), for instance by using the same notation as lecture slides and being tested to work with key examples covered in the subject(s). The applets generally targeted conceptual understanding by providing visualisations of mathematical & statistical concepts, rather than being intended as computational tools or sources of endless 'drill and practice' exercises, as these tasks are better suited to other platforms. A more detailed description of the approach taken by the project to identify teaching & learning needs and to design and develop the applets was reported in (Morphett, Gunn, & Maillardet, 2015).

² These two were *Normal approximation to the binomial distribution* and *Cobwebbing a difference equation*.

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The applets have so far been used in 9 subjects offered by the School of Mathematics and Statistics. These are listed above in Table 1. These include 2 large first-year subjects and a core second-year Mathematics & Statistics subject. Some applets are also being used in subjects taught by the School of Ecosystems and Forest Science and the Melbourne School of Psychological Sciences. Many of the applets are potentially relevant to other subjects from the School of Mathematics and Statistics or elsewhere in the University, so it is possible that the applets will find further deployment in additional subjects in the future. Some applets are also being used at other institutions, though we do not have concrete data on such use. Some applets, particularly those relating to introductory statistics, have the potential for use in secondary schools to support new statistical content in the revised VCE curriculum, though this potential has not yet been realised.

The way that the applets were used varied from subject to subject, but typical uses included demonstrations in lectures, use in one-on-one consultation, and optional use by students as a supporting resource on the LMS. Some subjects also incorporated applets into assignments, LMS quizzes or lab class activities.

Supporting resources. In addition to the applets, the project also produced additional resources to support the use of applets in teaching and learning. These resources included

- **Project website.** The website, www.melbapplets.ms.unimelb.edu.au, hosts the applets and other supporting resources described below. Applets are categorised on the website by topic and by subject code for easy access by teaching staff or students.
- **Instructors' notes.** These notes give an overview of the applet, highlight some aspects of the applet that are pedagogically relevant, and suggest ways that instructors may use the applet in their teaching. Currently, such notes have been written for 4 applets.
- **Online tutorial activities.** These are interactive webpages with a step-by-step activity making use of an applet to explore a particular concept. Two such tutorials have been produced, for [confidence intervals and hypothesis testing](#) and for [statistical power](#).
- **How-to guide for embedding applets in LMS.** The project produced a guide showing step-by-step how to embed a GeoGebra applet in an LMS page (including regular items, announcements or online quizzes). The guide is available at http://www.melbapplets.ms.unimelb.edu.au/?page_id=201.

We did not attempt to provide instructors' notes or online tutorials comprehensively for every applet or subject involved in the project. Instead, we produced a sample of such resources as 'exemplars' of each form. These were intended to serve as illustrations of what is possible and to provide a template for the development of more such resources in the future, if needed.

Impact on students and learning. The applets listed above have so far been used in 9 subjects offered at the University of Melbourne, primarily first and second-year subjects. These subjects have a combined enrolment of over 5000, and over 2500 distinct students per year. To investigate the impact of the project's resources on student learning, we surveyed students in several subjects. Students in 5 subject iterations were surveyed, with a total of 263 responses. Of the respondents, 82.9% agreed or strongly agreed that the use of the project's applets improved their understanding of concepts from the subject. Further details of the surveys and results are given in Appendix 1.

Impact on staff and professional development. Over 20 academic staff from the School of Mathematics and Statistics were involved in the project in some way, either by contributing to applet design, by using applets in their teaching, or by providing feedback on resources as they were developed. The staff came from a range of areas of mathematical and statistical expertise and taught at various levels and subject areas. The project used a cycle of design, feedback and refinement to develop the resources. As part of this process, applets under development were provided to relevant academics, who were encouraged to give feedback with particular reference to whether the applets met their teaching needs. In some cases, academics were prompted with

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specific questions, such as what terminology or notation should be used in the applet, what key examples they would want the applet to support, or what additional functionality would be needed to make effective use of the applet in their teaching. By actively seeking input and feedback from academics, the project prompted academics to reflect on their teaching practice.

The project team also ran workshops with academics to refine and test the applets. Two workshops were held. One focussed on statistics applets and targeted practicing statisticians and staff involved in teaching statistics; the other focussed on mathematics applets and targeted lecturers of core first and second-year mathematics subjects. Each workshop had about 10 participants and ran for about 90 minutes. In the workshops, brief demos of selected applets were given, and then participants were invited to play with the applets, individually or collaboratively, and give constructive feedback. These workshops prompted discussion about subtle pedagogical and design issues, brought to light through collaborative discussion, which were not identified in the previous feedback cycles. In this way, the project helped encourage collegiality and reflective practice in a non-confrontational and respectful way.

To investigate the impact of the project on staff, we are conducting interviews with teaching staff who were involved with the project. So far, two interviews have been held and several more are planned for the end of semester 1, 2016. The interviews investigate staff motivations for participating in the project, perceptions of effectiveness of the applets for learning & teaching, and the impact of the applets on teaching practice. We will not present results from this part of the project here, due to ongoing data collection and analysis, but the findings will be disseminated in future publications.

Dissemination. At time of writing, one academic paper about the project has been published (Morphett et al., 2015), reporting on the approach taken by the project to design applets, the strengths and weaknesses of GeoGebra as a technical platform for applet development, and some early outcomes of the project. Several more papers are in preparation or are planned, including a discussion of the design principles underpinning the development of the applets, and a case study of the use of applets to support conceptual understanding and reasoning in statistics. In addition, presentations about the project were made at several conferences and forums, including Elephant Delta 2015 (The Tenth Southern Hemisphere Conference on the Teaching and Learning of Undergraduate Mathematics and Statistics, Port Elizabeth, South Africa, 2015) and ANZMC (8th Australia-New Zealand Mathematics Convention, Melbourne, Australia, 2014).

Technical infrastructure. A stated aim of the project was to develop (with the assistance of Learning Environments) the necessary technical infrastructure to host GeoGebra-based applets on the LMS, to incorporate them into online quizzes and other LMS-based activities, and to obtain analytics data from their use. At the start of the project, technical limitations of the LMS and GeoGebra systems meant that it was difficult to embed GeoGebra applets into the LMS. Fortunately, recent updates to the LMS system and GeoGebra software eliminated these limitations automatically. It is now easy to embed GeoGebra applets into the LMS, including into online quizzes, without great technical expertise. Hence it was not necessary to seek Learning Environments' assistance with this, beyond some preliminary meetings early in the project. This allowed some project funds previously allocated to Learning Environments support to be repurposed for further resource development. A screenshot of an applet embedded in an LMS quiz is shown in Figure 2. As for analytics, by embedding applets into the LMS, usage data can be obtained using normal LMS analytics functionality. Unfortunately, technical problems with LMS subject reports during 2015 prevented us from obtaining detailed analytics data so we have not been able to investigate usage patterns of applets in detail or the extent to which such analytics data is insightful regarding student learning or behaviour. However, the necessary infrastructure for collecting such data is already in place so this could be investigated in the future once LMS reporting functionality is restored.

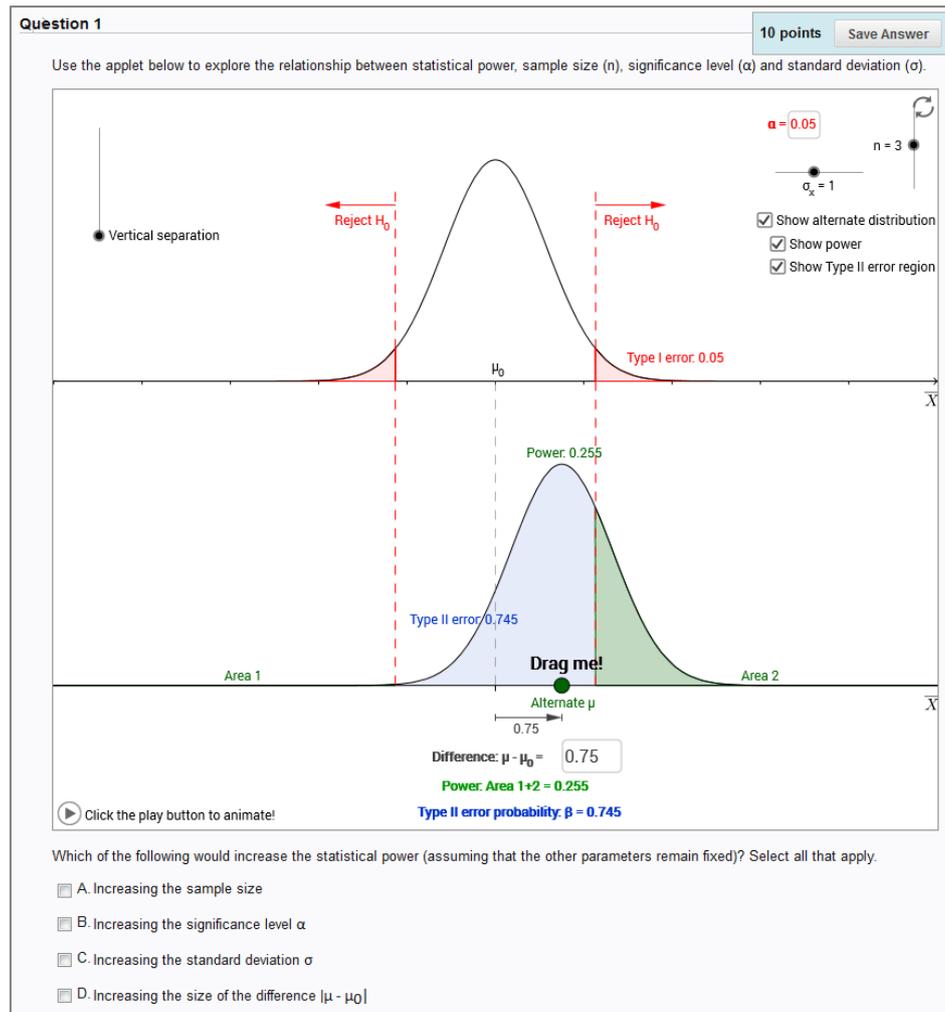


Figure 2: Screenshot showing a GeoGebra applet incorporated into an LMS quiz.

Pool of expertise. The three project team members, as well as seven postgraduates who were engaged as research assistants, gained valuable experience in the design, development, evaluation and use of applets in undergraduate teaching & learning. This, in addition to the involvement of various academic staff described earlier, provides a pool of technical and pedagogical expertise in the design, development and use of applets in teaching and learning. This pool could be drawn upon in the future for further applet development or related projects.

Future directions

There are several promising avenues for further work. Evaluation of the project's impact on teaching staff is ongoing, with additional staff interviews planned for mid-2016. We hope to focus particularly on teaching staff who are now using our applets but who were not involved in the original design and development process, and to look for evidence of any change in teaching practice or additional reflection on teaching as a result of using the applets.

There is also potential for further integration of applets with assessment. During 2015, applets were linked with assessment in two subjects (MAST10010 Data Analysis 1 and MAST10016 Mathematics for Biomedicine) by explicitly requiring students to use applets as part of written assignments. The applets also have the potential to enhance online assessment by providing additional interactivity and feedback, and may support assessment of higher-order cognitive domains by allowing direct and interactive engagement with concepts. Some possibilities for embedding applets (both technically and pedagogically) into online quizzes have been explored during 2015, but many have not yet been

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implemented in teaching. We hope to more extensively trial the use of applets in online quizzes in semester 2, 2016. This may lead to further publications or documentation to assist other academics seeking to using applets in their assessment.

Finally, some of the resources developed by the project are potentially relevant at secondary school level, for instance to support teachers implementing new content in the VCE curriculum. One possible route for engagement with secondary teachers is via the Mathematical Association of Victoria (MAV).

Budget/Expenditure

Item	Budget	Actual	Comments
Casual research assistance to implement new applets & supporting materials	\$7,000	\$9,600.34	Casual academic salary, 200.3 hours @ Research Assistant grade 2 rate for resource development
Technical assistance and advice from Learning Environments	\$1,725	\$0	LE technical assistance was not required so the allocated funds were re-purposed for further resource development
Costs associated with project evaluation – room/equipment hire, etc	\$1275	\$338.90	Casual academic salary, 7.1 hours @ Research Assistant grade 2 rate for assistance with evaluation. Room & equipment use was provided in-kind by School of Maths & Stats, reducing evaluation costs. Unused allocated funds were re-purposed for further resource development.
TOTAL	\$10,000	\$9,939.24	

Please return this report to: landt-grants@lists.unimelb.edu.au within six months of project completion.

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Appendix 1: Summary of student survey results

Student surveys were conducted in several subjects in which applets from the project were used. The surveys were run as online surveys and delivered to the students via the LMS and email. The questions in each survey varied according to the subject in question and the stage of the project, but all included a question asking whether the students found that the applet(s) improved their understanding of subject content. The table below summarises the survey results.

Subject	# Responses (% of class)	Question wording	% Agree/ Strongly agree	Relevant applets
MAST10016 Mathematics for Biomedicine <i>Semester 2, 2014</i>	38 (21%)	I found that the applets improved my understanding of concepts from this subject.	89.5%	Iterating a difference equation Cobwebbing a difference equation Population genetics by FHW model Exploring an ODE
MAST10010 Data Analysis 1 <i>Semester 2, 2014</i>	84 (37%)	In developing my understanding of the normal approximation to the binomial distribution I found the applet to be: (Extremely helpful, Helpful, Not particularly helpful, Undecided)	75.0% (Helpful/ Extremely helpful)	Normal approximation to the binomial distribution
MAST10006 Calculus 2 <i>Semester 1, 2015</i>	70 (6.0%)	The sequences and series Geogebra applet helped me understand the behaviour of sequences and series.	84.3%	Sequences and series
MAST20026 Real Analysis <i>Semester 1, 2015</i>	18 (8.5%)	I found that the applets improved my understanding of concepts from this subject.	83.3%	Convergence of a sequence Convergence and continuity of a function Differentiability of a function Riemann sums and partitions
MAST10010 Data Analysis 1 <i>Semester 2, 2015</i>	53 (18%)	I found that the applets improved my understanding of concepts from this subject.	88.7%	Normal approximation to the binomial distribution Normal probability plot and CDF Power of a hypothesis test Cls, hypothesis testing and p-values Partitioning of variability in regression Partitioning of variability in ANOVA
Overall:	263		82.9%	

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The surveys also included questions addressing the ease-of-use of the applets, whether students experienced technical problems, and in what contexts students used the applets, and sought general feedback or suggestions for the applets. As we are primarily interested in evidence of impact on student learning, we will not consider these other questions here, except to note that the results from these questions were fed back into the applet development and refinement process.

References

Morphett, A., Gunn, S., & Maillardet, R. (2015). *Developing interactive applets with GeoGebra: processes, technologies*. Paper presented at the Elephant Delta: 10th Southern Hemisphere Conference on the Teaching and Learning of Undergraduate Mathematics and Statistics, Port Elizabeth, South Africa <http://www.delta2015.co.za/images/Proceedings.pdf>