USING THE ISLAND TO TEACH STATISTICS THROUGH DATA INVESTIGATIONS: A PILOT PROJECT IN AUSTRALIAN SECONDARY SCHOOLS

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ABSTRACT

Declines in secondary school students' attitudes towards, and participation in, mathematics and science are cause for concern. In 2012, a report from the Office of the Chief Scientist called for universities and schools to develop partnerships aimed at improving mathematics and science education in schools. Responding to this call, this pilot project used an online simulation of a human population, known as the *Island* (Bulmer & Haladyn, 2011), to develop innovative activities for teaching statistics through data investigations within the Statistics and Probability strand of the Australian Mathematics Curriculum. The *Island*-based activities aimed to engage students in meaningful and realistic statistical practice and thereby improve their attitudes towards statistics. The resources were piloted in four partnered secondary schools from the northern suburbs of Melbourne in years 8 to 11 mathematics classes. Questionnaire data from students' attitudes towards statistics before and after completing the project activities were collected from 237 students. The results found statistically significant increases in positive attitudes towards statistics, however, students' attitudes towards career prospects in statistics were resistant to change and competency significantly declined. This paper discusses the limitations of these findings and the future directions for a national project.

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INTRODUCTION

Australia must increase the rates of science and mathematics graduates if it is to remain economically competitive (Australian Industry Group, 2013; Office of the Chief Scientist, 2012). Unfortunately, Australia has been failing to the meet the demand for science and mathematics graduates required by government, education and industry (Australian Industry Group, 2013; Bourguignon, Dietrich, & Johnstone, 2006; Edwards & Smith, 2009). Graduates with mathematical and statistical backgrounds, in particular, have become increasingly important as our society relies more and more on the use data-based decision making. Unfortunately, Australia ranked 23rd out of 26 countries within the Organisation for Economic Co-operation and Development (OECD, 2015), with only 0.46% of all Australian graduates having a mathematical or statistical background. The OECD average for mathematics and statistics graduates was 1.19%. Mathematical ability is not the cause, either, as Australia was ranked significantly higher than the OECD average mathematical ability (OECD, 2014). This suggests other factors are at work in determining low graduate rates. Data from the Victorian Auditor General (2012) highlighted concerns regarding changes in students' attitudes towards mathematics and science between primary and secondary school. Based on a survey of eight primary and eight secondary schools in Victoria, the report found that student interest in science and mathematics subjects dropped from 93.3% and 74.8% in year six to 62.9% and 41.9% in year nine, respectively. Data reported by Kennedy, Lyons and Quinn (2014) also demonstrate that since 1992, participation rates in science and mathematics classes have shown concerning downward trends.

Attitudes are important and particularly so in statistics, which is a dedicated strand within the Australian Mathematics Curriculum F-10 (ACARA, 2015). A meta-analysis of 17 studies by Emmioğlu and Yesim (2012) found a consistent negative relationship between student attitudes towards statistics and achievement. Ramirez, Schau and Emmioğlu (2012) hypothesize that student attitudes drive engagement in learning and determine later use of these skills. This implies that if students are disengaging during secondary school statistics classes, they will be very unlikely to pursue statistics-related careers. Recognising this problem, the Office of the Chief Scientist released a report in 2012 entitled "*Mathematics, engineering & science in the national interest*" (Office of the Chief Scientist, 2012), in which many recommendations were made to improve the state of science, technology, engineering and mathematics (STEM) education in Australia.

The Office of the Chief Scientist raised concerns around the teaching of mathematics and science in schools, commenting that common practices were too didactic and disinteresting. The report urged schools and universities to develop innovative approaches to bring the "practice" and relevancy of mathematics and science into the classroom to improve student interest. The Chief Scientist's report echoes what many statistics educators have long been advocating, that the teaching of statistics should be through data investigations as it aligns with real world statistical practice (Holmes, 1997; MacGillivray & Pereira-Mendoza, 2011; Marriott, Davies, & Gibson, 2009; Wild & Pfannkuch, 1999). Students who complete statistical data investigations gain valuable experience working through the entire cycle of an investigation from initial problems, planning, data collection, analysis and drawing conclusions. Such investigations also draw close parallels with the Science Inquiry strand of the Australian Science Curriculum (ACARA, 2015), opening the doors to interdisciplinary teaching (Watson, 2014). However, schools and teachers face many barriers to teaching statistics through data investigations including practical and ethical constraints, and the necessary know-how.

This pilot project, briefly outlined in Huynh and Baglin (2014), aimed to develop and pilot an innovative technological approach to teaching statistics through data investigations in year 9 and 10 mathematics and science classes. The project made use of the *Island* (http://island.maths.uq.edu.au/) to overcome the challenges for implementing statistical data investigations in schools, while still engaging students in a realistic simulated context (Bulmer & Haladyn, 2011). The *Island* is a free, online, human population simulation that provides students with a virtual playground for practicing statistical data investigations. The *Island* is explored by clicking between the 36 villages that are home to approximately 9000 virtual residents. Simulation models govern the population's births, deaths, health, social lives and residency. Each resident has their own personal story and genetic code that are linked to their appearance and reactions to over 200 interacting tasks controlled by realistic statistical models. Task categories include surveys, blood tests, physiological measures, mental tasks and exercise. Archival information can also be gathered relating to births, deaths, marriages, demographics, medical records and relationships. Many different types of statistical data investigations are made possible, including surveys, observational studies and experiments. The *Island* also educates students about the practicalities of investigations as Islanders have sleep/wake cycles and can refuse consent, drop out (withdraw consent or die), lie or become ill.

The *Island* has been utilised extensively in Australian universities to improve student engagement in statistical data investigations without the practical and ethical limitations imposed by real human research. University students using the *Island* have reported high levels of engagement and improved statistical thinking (Baglin, Bedford, & Bulmer, 2013; Baglin, Reece, Bulmer, & Di Benedetto, 2013; Bulmer, 2010; Linden, Baglin, & Bedford, 2011) and preliminary work in secondary schools has suggested similar benefits (Huynh, Baglin, & Bedford, 2014). This article reports data collected as part of a pilot project that was used to determine if students' attitudes towards statistics change after engaging in the project's activities.

PROJECT ACTIVITIES AND TEACHER MANUAL

The pilot project's main outcome was the development of a free teacher manual, *Island in Schools*: *Innovating the Teaching of Statistics and Data Analysis in Years 9 and 10,* that provided a series of classroom-ready *Island*-based activities (request a copy by emailing the first author). The activities were aligned to the Data Representation and Interpretation content area of the Statistics and Probability strand of the Year 9 and 10 Mathematics Curriculum, but also drew links to the Scientific Inquiry Skills strand of the Science Curriculum (ACARA, 2015). The following ten activities were developed along with an open-ended investigation project: 1) Gathering samples from a population – an introduction to the *Island*, 2) The effects of temperature on exercise performance, 3) Balance as a repeated measures design, 4) Reaction time and adrenaline, 5) Gender and mental health survey, 6) Height and liver size, 7) Peak flow meter and age, 8) Ball bouncing and age, 9) *Island* climate longitudinal data, 10) Birth rates over time and 11) Student data investigation project.

Each worksheet contained a problem statement, a detailed description of the data collection process to be completed on the *Island*, space to report and process the data collected, and questions to assess the students' understanding of the activities and their ability to interpret data and draw conclusions in context. The activities were not intended to teach the statistics curriculum content, but were included to assist teachers with enriching the classroom experience. Most teachers used the activities to motivate and open opportunities to teach elements of the curriculum as the need arose. After reading the activity outline and research plan, students logged into the *Island* to collect their respective data using sampling methods. Students completed their data collection on the *Island* using portable computing devices, typically iPads or laptops. Some classes used school computer laboratories. Once the data collection process was completed, students would answer the activity questions, which required students to reflect on data representation and interpretation covered in the curriculum and relate back to the context of the research problem.

The student data investigation activity provided a teacher outline for how to have students conduct their own open-ended investigations using the *Island*. The *Island* contained in excess of 200 tasks and activities, so students were likely to find a topic of interest to them. The open-ended investigation was seen as a capstone experience for the Statistics and Probability strand of the Mathematics Curriculum as students would be required to manage their own investigations without much guidance. A number of partnered schools chose to complete the data investigation project, with students presenting their findings in poster formats.

PILOT AND EVALUATION

Approximately 20 mathematics coordinators from secondary schools in the northern suburbs of Melbourne, Victoria, were mailed an invitation letter to join the project. Four schools joined the project: two government schools and two private schools. Data pertaining to students' attitudes towards statistics before and after engaging in the *Island*-based activates are reported in this paper from a total of 237 questionnaires returned from the four partnered schools, representing nine year 9, one year 10 and two year 11 mathematics classes and one year 8 science class. However, reported sample sizes are typically less due to missing values. Almost all students in each class completed the questionnaires, but an exact response rate could not be determined as the study was not privy to class lists or attendance. The number of activities/projects completed by each class ranged from one to four, with the majority (8/13, 62%), implementing three *Island*-based activities.

MEASURES AND PROCEDURE

Prior to commencing the study, a baseline measurement of student attitudes was acquired via a 22-item pre-test questionnaire. These items were loosely adapted and modified from the Expectancy–Value Theory (EVT) of Achievement Motivation (Wigfield & Eccles, 2000) and were rated on a five point scale ranging from 1) Strongly disagree to 5) Strongly agree. Attitudes are affective responses that accompany a behaviour initiated by a motivational state (Guthrie & Knowles, 2001) and can be linked to understanding motivational processes. Fourteen items (Items 2 – 15) on the pre-test pertained specifically to attitudes towards statistics and have been listed in Table 1. The administration of the questionnaire was approved by the authors' institution and by the Victorian Department of Education and Training and relevant school principals. The questionnaire was used to evaluate the associated impact of the activities on students' attitudes towards statistics. A project member was on hand to deal with any technical difficulties and in some cases to assist the teacher in the delivery of the first *Island* activity. After the first class, the teachers were left to implement the remaining activities and *Island*-based project and a later time was arranged for the project team to administer the post questionnaire following the completion of the *Island*-based activities.

RESULTS

Exploratory factor analysis (EFA), using *Factor* (Lorenzo-Seva & Ferrando, 2006), was performed on the 14 attitude items. The EFA analyzed the polychoric correlation matrix, which is advised when ordinal rating scale items have been used (Baglin, 2014; Timmerman & Lorenzo-Seva, 2011). Parallel analysis (PA) using minimum rank factor analysis (Shapiro & ten Berge, 2002; ten Berge & Kiers, 1991; Timmerman & Lorenzo-Seva, 2011) was chosen for the retention and extraction technique, respectively. Three stable factors were identified after removing item 14 due to a poor loading. Table 1 provides the final rotated solution using the oblique Promin method (Lorenzo-Seva, 1999). The three factors identified included *Attitudes, Career Prospects* and *Competency*. Table 1 reports and organises each item into these three factors.

Table 1: Attitudes Towards Statistics Questionnaire - Rotated Factor Loadings, Reliability and Variance Explained.

Item	Attitudes	Career Prospects	Competency
2. Statistics is enjoyable and stimulating for me	**.885**	-.061	.066
3. I enjoy learning and reading about statistics	**.908**	-.032	.015
4. I look forward to my statistics lessons	**.901**	-.015	-.023
5. I am interested in the topics I learn in statistics	**.800**	.064	.013
6. Making an effort in statistics is worth it because it will help me in the work that I want to do after finishing school	.027	**.852**	-.025
7. Learning statistics is worthwhile for me because it will improve my career prospects and chances in getting a job	.018	**.832**	.038
8. Statistics is an important subject for me because I need it for what I want to study after finishing school	.013	**.874**	-.099
9. I will learn many things in statistics that will help me get a job	-.023	**.803**	.094
10. I am just not good at statistics	-.119	.013	**-.464**
11. I learn statistics quickly	.197	-.043	**.570**
12. If I put in enough effort, I can succeed in statistics	-.025	.110	**.733**
13. Whether or not I do well in statistics is completely up to me	-.130	-.005	**.705**
14. If I had different teachers, I would try harder in learning about statistics	-	-	**-**
15. If I wanted to, I could do well in statistics	-.068	-.058	**.814**
Reliability[a]	.933	.911	.827
% Variance [b]	51.93	17.71	15.66

Note. Item 14 removed due to poor loading. Rotated factor loadings reported. Item factor loadings bolded belong to the respective column's factor. EFA Matrix: Polychoric correlations, Extraction: MRFA, Retention: PA, Rotation: Promin, [a] Mislevy and Bock (1990). [b] Percentage of common variance explained based on MRFA.

Descriptive statistics and the percentage of students' agreement (those rating either "Agree" or "Strongly agree") to each item on the pre and post questionnaire are reported in Table 2. Table 3 reports the descriptive statistics for the factors' scores on the pre and post questionnaire. While attitude ratings improved, career prospects remained largely unchanged and competency reduced. To determine if any of these changes were statistically significant, three paired sample *t*-tests were performed. The tests found that attitudes were associated with a statistically significant mean improvement, career prospects remained stable and competency was associated with a statistically significant average decline (see Table 3). Cohen's *d* values, adjusted for paired data, were reported as measures of standardized effect size.

DISCUSSION

This pilot project developed and piloted innovative, classroom-ready statistical data investigation activities based on the *Island* in order to enrich the teaching of statistics within the Australian Mathematics Curriculum. A teacher manual containing the activities can be obtained by emailing a request to the first author. The *Island*-based activities engaged students in meaningful and realistic virtual statistical practice and the entire process of a statistical data investigation. Students were required to understand the research problem, plan and implement data collection, process and analyse data and interpret data in context. Based on the pre and post questionnaire data from over 200 secondary students across four partnered schools, the activities were associated with statistically significant improvements in attitudes towards statistics, no change to career prospects and a statistically significant decline in competency. Without a comparison group that did not complete the activities, it is impossible to solely attribute these associated changes to the activities. However, the associated improvement to students' attitudes towards statistics was promising. The significant decline in competency was also difficult to interpret without a meaningful comparison. It is possible that students' initially overestimated their competency, which later declined on the post questionnaire as they had a better appreciation of the challenging nature of statistical practice. Despite this decrease, it was reassuring that attitudes still improved. The results also suggested that students' perceptions of career prospects in statistics may be resistant to short-term change, despite improved attitudes.

Table 2: Descriptive Statistics and Percentage Agreement to the Attitudes Towards Statistics Questionnaire Items Pre and Post.

			Pre			Post		
	Item	*n*	*M*	*SD*	% Agree	*M*	SD	% Agree
Attitudes	2.	236	2.64	1.08	24.6	2.77	1.09	23.7
	3.	234	2.67	1.13	27.4	2.75	1.18	27.4
	4.	235	2.57	1.14	23.4	2.69	1.18	24.7
	5.	230	2.84	1.11	31.3	2.87	1.14	30.9
Career Prospects	6.	235	3.13	1.25	40.0	2.93	1.18	29.8
	7.	236	3.30	1.19	44.9	3.08	1.15	37.7
	8.	236	2.69	1.10	19.5	2.68	1.11	20.8
	9.	237	2.93	1.09	27.0	2.95	1.09	30.0
Competency	10[a].	232	2.45	1.10	16.8	2.44	1.14	18.5
	11.	232	3.41	1.03	48.7	3.41	1.09	53.4
	12.	232	4.26	0.89	85.3	4.15	1.00	78.0
	13.	236	3.90	1.07	66.9	3.92	1.04	66.9
	14.[b]	231	2.70	1.41	31.6	2.79	1.46	33.3
	15.	233	4.13	0.99	80.3	3.91	1.07	70.0

Note. *n* = Sample size, *M* = mean, *SD* = standard deviation, % Agree = % of students rating item as "Strongly Agree" or "Agree", [a] = item has been reversed coded, [b] = non-loading item based on EFA.

Table 3: Descriptive Statistics, Paired Sample *t*-test Results and Cohen's *d* for Pre and Post Statistics Attitudes Factor Scores

		Pre		Post					
	n[a]	*M*	*SD*	*M*	*SD*	*t*	*p*	*d*[b]	95% CI
Attitudes	221	2.67	1.02	3.02	0.86	4.94	<.001*	0.33	0.20, 0.47
Career Prospects	229	2.84	0.74	2.83	0.70	0.18	0.86	0.01	-0.14, 0.12
Competency	218	3.86	0.70	3.45	0.62	8.32	<.001*	-0.56	-0.70, -0.42

Note. [a]*n* = sample size based on questionnaires with no missing data for a factor's items, [C]Cohen's *d* based on adjustment for paired data. *M* = mean, *SD* = standard deviation, *t* = test statistic from a paired sample *t*-test and *p* = *p*-value. * $p < .05$, statistically significant change.

The low level of agreement to the attitude items in Table 2 highlight the relatively poor perceptions students hold towards statistics. For example, only 24.6% of students agreed that statistics is enjoyable and stimulating on the pre-test. Interestingly, this individual item slightly decreased to 23.7% on the post questionnaire, despite the overall attitude towards statistics factor (a composite score identified by the EFA) significantly improving. This suggests that improvements were being made to the disagreement side of the scale, by shifting responses from strong disagreement into slightly less disagreement or neutrality. Such a change was desirable, but was unlikely to be the required shift needed to inspire a new generation of statisticians. The results of this study suggest, assuming the associated changes in students' attitudes are attributable to classroom experiences, that change will likely be modest and will require continued efforts across year levels. Further research is also needed to refine the activities, better understand their impact across diverse schools, examine the variation between different *Island* activities, and learn under what circumstances the activities have their greatest impact on attitudes. Further research should also investigate the impact of these activities on student learning outcomes and compare the activities to other methods for more meaningful comparisons. Finally, future studies should also consider examining additional factors of the EVT model (such as effort) via interviews with respondents, as this paper has only focused on the effects of motivation on attitudes.

This pilot project laid the foundation for the *Island*-based activities and resources and provided the project team with an important experience working with secondary school partners. This experience and the feedback obtained from teachers highlighted a number of required improvements to be carried out in 2015. The project team was successful in gaining additional funding from the Australian Government Department of Education through the Australian Maths and Science Partnership Program (AMSPP). The 2015 project will improve the pilot resources by creating a stronger curriculum alignment to the Statistics and Probability strand of the Mathematics Curriculum, cover years 7 to 10, and provide teachers with access to online professional development content to support their preparation for classroom implementation. The new resources will align to the new version of the *Islands*, currently available at http://smp-island.smp.uq.edu.au. Those interested to learn more about the national project and access the project resources are encouraged to contact the authors. This pilot project and the resulting national project both aimed to improve the teaching of statistics in Australian secondary schools by engaging students in the statistical data investigation process using innovative educational technology. Further research is needed to determine if and to what degree these improvements impact students' attitudes and interest in statistics and related career pathways.

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