DEVELOPING POSTGRADUATE STUDENTS STATISTICAL THINKING IN UNIVERSITY:
EVALUATION OF A STATISTICAL THINKING LEARNING ENVIRONMENT MODEL

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Abstract

Introduction: Statistics education is critical for researchers in health disciplines as it underpins quantitative approaches to empirical research. This presentation evaluates a model for an interactive, postgraduate level statistics course in university that is designed to develop students’ statistical reasoning and thinking. The model used for this study is called ‘Statistical Thinking Learning Environment’ (STLE) and is underpinned by the Constructivist Theory of Learning.

A constructivist theoretical approach to learning maintains that new knowledge and understandings are based on our existing knowledge and beliefs and grounded in our experiences. We learn by doing. And when we learn, our previous knowledge does not go away; it is integrated with the new knowledge. The implication of current theories of learning is that good education practice consists of designing learning environments that motivate students to construct knowledge. This involves activities that provide students with many opportunities to think, reason, and reflect on their learning, as well as discussing and reflecting with their peers.

Method: The STLE model was developed to enhance students understanding of statistics, their ability to think and reason statistically, and apply the statistical skills in practice. The STLE is the interactive combination of course materials, class activities and culture, discussion, online technology, teaching approach, and assessment. 90 students in the 2010 cohort were invited to participate in study to evaluate the six principles of the model, which are: 1. Focus on developing central statistical ideas rather than on presenting set of tools and procedures. 2. Use real and motivating data sets to engage students in making and testing research hypotheses. 3. Use classroom activities to support the development of students’ reasoning and critical thinking. 4. Integrate the use of appropriate technological tools that allow students to test their inferences, explore and analyse data, and develop their statistical reasoning. 5. Promote classroom discourse that includes statistical arguments and sustained exchanges that focus on significant statistical ideas. 6. Use assessment to learn what students know and to monitor the development of their statistical learning as well as to evaluate instructional plans and progress. Mixed research methods using both qualitative and quantitative approaches were used to evaluate the effectiveness of STLE method to enhance students learning and applications of their learning in their research and work related projects.

Results: The participants who responded to both qualitative interview and quantitative survey indicated that the STLE model significantly enhanced their critical thinking development and enhanced their learning and research skills in quantitative research.

Discussion and conclusions: STLE model was an effective approach to statistics education and the six principles outlined earlier are key elements in developing a class where students are engaged in making and testing inference using data, discussing and explaining statistical reasoning, and focusing on the implication and implementation of statistical principles in further research and work.

Keywords: Teaching; Active Learning; Statistical Thinking; Postgraduate Statistics Course; Constructivism.
1 INTRODUCTION

Statistics education in postgraduate students has been critical for researchers in health disciplines as it underpins quantitative approaches to empirical research. In health related disciplines, quantitative research in postgraduate students often links to a problem-based learning environment where students have to direct their own learning and carry out an independent research project. Due to the diverse information resources in health disciplines, and the need to provide students with access to knowledge that is pluralistic, lecturers in statistics will rarely be able to rely on one relevant chapter in a statistical textbook to answer all student questions regarding their research problems. In addition, the goal of education in the Information Age is to prepare students to use their skills to solve real world problems; yet, education has been criticised for failing in this task. The common reason cited is that University learning experiences in statistics are so different from real world experiences that students cannot transfer the skills between the two environments [1-4]. Neither does it suffice to provide a certain formula at hand, or to simply plug a statistical procedure into a problem that will solve problems across all health disciplines. It is therefore critical that student learning is problem based and allows students to reflect on the information available to them as well as inform how they go about acquiring content. Based on this, what they take away becomes more than just procedure and information—it should be knowledge which informs and transforms their thinking, actions and practice so they can apply these abilities into their research and professional practice.

The problem-based statistics learning is fraught with complexity in terms of the understanding of statistical concepts. Hence, if students are not engaged in critical thinking, the meaning-construction process afforded by problem based learning is not supported, and learning is hindered [5]. Moreover, as learners and later on as practitioners in their careers who are constantly developing their skills, it is important that they reflect on how they respond to different situations, so that they can tackle problems through critical thinking, and thoughtful and considered actions using statistical methods.

The contemporary view of learning according to constructivist approaches is that learning requires the building of conceptual structures through reflection and abstraction. Since each learner has to construct his or her knowledge, concepts cannot be transmitted from teacher to learner by means of words. Learning occurs only when the learners are actively involved in the construction and organisation of concepts [2]. In statistical teaching, constructivism focuses our attention on how people learn. It suggests that statistics knowledge results from people forming models in response to the questions and challenges that come from actively engaging math problems and environments - not from simply taking in information. We learn by doing. And when we learn, our previous knowledge does not go away; it is integrated with the new knowledge. In addition, knowledge is highly related to the context and environment in which the learner experiences and constructs the knowledge [2, 6]. In other words, understanding is informed by experience. Constructivists emphasise cognitive experience in authentic activities. To be authentic does not mean the context has to be the real world of work; rather, learning activities should employ the type of tasks that represent real world practices [2].

The implication of a constructivist approach to learning is that good education practice consists of designing learning environments that motivate students to construct knowledge. This involves activities that provide students many opportunities to think, reason, and reflect on their learning, as well as discussing and reflecting with their peers. According to Jonassen [7], the aim of education is to teach higher order cognitive skills such as critical thinking and to cultivate dispositions to apply those skills. A cluster of the elaborative mental abilities to achieve this includes reasoning, judgement, critical thinking and analysis of complex situations [8, 9]. To achieve this educational goal, the implication of current theories of learning to the postgraduate statistical course teaching consists of designing learning environments that stimulate, motivate and influence students to construct knowledge, to reason, and to reflect in learning. The challenge in teaching is to create experiences that engage the student and support his or her own explanation, evaluation, communication, and application of the statistical models needed to make sense of these experiences.

This paper evaluates a model for an interactive, postgraduate level statistics course in university that is designed to develop students’ statistical reasoning and thinking. The model used for this study is called ‘Statistical Thinking Learning Environment’ (STLE), which is built on the constructivist theory of learning. The STLE model is the interactive combination of teaching approach, course materials, class activities and culture, discussion, online technology, and assessment. This involves activities that
provide students many opportunities to think, reason, and reflect on their learning, as well as to discuss and reflect with their peers, and encourage student effort through providing feedback on their tutorial work. In the teaching process, student thinking was initiated by research problems, guided by instructions, and allowed opportunities to construct knowledge for themselves, as well as opportunities to participate in peer group activities. It was developed to enhance students understanding of statistics, their ability to think and reason statistically, and apply the statistical skills in practice.

The main question addressed by this study is: Does the STLE approach develop students critical thinking and increase students’ capacity to undertake research?

2 METHODOLOGY

2.1 Methods

The study employed a cross-sectional design and a mixed method approach to evaluate the effectiveness of STLE approach in facilitating students critical statistical thinking, increasing their capacity to undertake research and facilitating social interaction in statistics course. Individual interviews were used to investigate student opinions of the implementation process of the STLE approach in statistical teaching; and a survey was used to collect data on STLE approach and its relationship with students critical thinking and increasing their capacity to undertake research and social interaction.

2.2 Participants

The sample was taken from students at the end of their study of the statistics course in major metropolitan University. These participants were undertaking either honours or postgraduate coursework programmes in health discipline areas including physiotherapy, medical science, human services, public health, nursing and midwifery, pharmacy, and dentistry. In the qualitative data collection a convenient sample was used. Five students from the previous semester and five students in the current semester participated in the interviews. Honours and postgraduate students were either individually approached and invited to complete the questionnaire by hand, or were directed by email to complete it online via a Survey Monkey website. A sample of 90 students was obtained. In all, there were a total of 34 useable responses to the quantitative survey. As is common in most local educational institutions in Australia, respondents were 60% domestic Australian, and 40% were intervention students who were from countries such as China, India, Indonesia, Malaysia, Taiwan, Hong Kong, Sweden, Canada, and Saudi Arabia. Approximately equal numbers of students across the schools were represented, and there was an approximately equal gender ratio.

2.3 Design of ‘Statistical Thinking Learning Environment’

The STLE model was developed to enhance students understanding of statistics, their ability to think and reason statistically, and apply the statistical skills in practice. The SRTE is the interactive combination of course materials, class activities and culture, discussion, online technology, teaching approach, and assessment, and has six principles of the model: 1. Focus on developing central statistical ideas rather than on presenting set of tools and procedures. 2. Use real and motivating data sets to engage students in making and testing research hypotheses. 3. Use classroom activities to support the development of students’ reasoning and critical thinking. 4. Integrate the use of appropriate technological tools that allow students to test their inferences, explore and analyse data, and develop their statistical reasoning. 5. Promote classroom discourse that includes statistical arguments and sustained exchanges that focus on significant statistical ideas. 6. Use assessment to learn what students know and to monitor the development of their statistical learning as well as to evaluate instructional plans and progress.

2.4 Measures of ‘Statistical Thinking Learning Environment’

In the qualitative data collection, semi-structured interview questions were asked to determine student opinions of the STLE approach and how it was relevant to their critical thinking, how it increased their capacity to undertake their research project. In the quantitative data collection, in order to capture the relationship between STLE and student critical thinking, increasing capacity to undertake research,
and social interaction, a questionnaire on STLE approach was employed. This was a 20 item self-reported questionnaire which measures STLE approach along four scales: critical reflection teaching method, problem based course design, research based course content, methods to inspire student’s learning. Participants rated their agreement on each item along a six-point Likert scale: 1 Definitely disagree, 2 Disagree to some, 3, Disagree a little, 4 Agree a little, 5 Agree to some extent, 6 Strongly agree. In the validation of the instrument, the Cronbach alpha level for the reliability of the four scales was 0.89, 0.86, 0.85, and 0.82 respectively. In further support of the validity of the instrument, a factor analysis was run to test the overall variance explained by the 20 questions. It was found that the 20 questions explained high level of 78.18% variance of the STLE approach. The high level of reliability and validity has shown itself to be useful as a measure of STLE approach, and was thus employed in the present research to answer the research questions. In addition to STLE scale, questions on student critical thinking, increasing capacity to undertake research, and social interaction were also asked on a six-point Likert scale.

2.5 Analysis

In order to gain insights into the patterns of students’ opinion of STLE approach, a descriptive analysis was run on the four STLE scales and three questions in student critical thinking, increasing capacity to undertake research, and social interaction. Inter-scale correlational analysis was also run on the four STLE scales. In order to find out how students in this STLE environment were developing their critical statistical thinking regression analysis was used to analyse the relationship between STLE and each of the outcome variables in critical thinking, enhancement of student learning, and facilitating social interaction.

2.6 Results

Respondents’ scale scores were calculated by averaging score for the items comprising each scale.

Table 1 gives an overview of the means and standard deviation for each scale in overall score and by gender.

<table>
<thead>
<tr>
<th></th>
<th>Overall score M(SD)</th>
<th>Male M(SD)</th>
<th>Female M(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical reflection teaching method</td>
<td>5.18 (0.57)</td>
<td>5.16(0.58)</td>
<td>5.19 (0.58)</td>
</tr>
<tr>
<td>Problem based course design</td>
<td>5.03 (0.78)</td>
<td>4.70 (0.89)*</td>
<td>5.27 (0.61)</td>
</tr>
<tr>
<td>Research based course content</td>
<td>5.08 (0.56)</td>
<td>5.09 (0.51)</td>
<td>5.08 (0.61)</td>
</tr>
<tr>
<td>Methods to inspire student’s learning</td>
<td>5.70 (0.46)</td>
<td>5.64 (0.50)</td>
<td>5.75 (0.44)</td>
</tr>
<tr>
<td>Critical thinking</td>
<td>5.26 (0.71)</td>
<td>5.07 (0.73)</td>
<td>5.40 (0.68)</td>
</tr>
<tr>
<td>Enhancement of learning</td>
<td>5.20 (0.84)</td>
<td>5.07 (0.91)</td>
<td>5.30 (0.80)</td>
</tr>
<tr>
<td>Gaining social interaction</td>
<td>4.91 (1.02)</td>
<td>4.85 (1.09)</td>
<td>4.95 (0.99)</td>
</tr>
</tbody>
</table>

Table 1 shows that consistent high scores were obtained in average scores of reflective thinking methods, problem based course design, research based course content, methods to inspire students to learn. The development of student critical thinking and increasing capacity to undertake research is also very high. This is in comparison with the score lower than 5 in student social interaction in the course. There is a statistically significant difference between male and female students in problem based course design, and this factor will be controlled into the regression model on the relationship between problem based course design scale and student critical thinking, increasing capacity to undertake research, and enhancing social interaction.
Table 2 tabulates the correlations of the four scales arising from the dataset.

### Table 2. Correlation between four scales of STLE approach

<table>
<thead>
<tr>
<th></th>
<th>Teaching method</th>
<th>Course design</th>
<th>Course content</th>
<th>Inspire students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching method</td>
<td>1</td>
<td>0.62***</td>
<td>0.77***</td>
<td>0.36**</td>
</tr>
<tr>
<td>Course design</td>
<td></td>
<td>1</td>
<td>0.64***</td>
<td>0.47***</td>
</tr>
<tr>
<td>Course content</td>
<td></td>
<td></td>
<td>1</td>
<td>0.48**</td>
</tr>
<tr>
<td>Inspire students</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**P < 0.01, *** P<0.001

This table shows moderate to high correlations between the four scales; of particular note is these figures provide some support for the theoretical postulation that these constructs are important to constructivist learning environment theory, especially as shown by the high correlation between critical reflection teaching method and problem-based course design; and critical reflection teaching method and research-based course content; as compared with that between critical reflection teaching method and methods to inspire students to learn.

Table 3 presents regression analysis results on the relationship between each of the four STLE scales and student critical statistical thinking development, enhancement of learning and social interaction. The combined scores are used for each aspect of STLE measure to analyse the relationship between each of the STLE approach with student critical thinking development and enhancement of learning in regression analysis. The probability level less than 0.05, regression coefficient above 0.20, and correlation coefficient above 0.40 are regarded as having statistical significant impact, the results are show in the table below.

### Table 3. Relationship between STLE approach and student critical thinking, learning and social interaction development

<table>
<thead>
<tr>
<th>Variables</th>
<th>Student critical thinking and quantitative skills</th>
<th>Student learning and study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression coefficient (95% CI)</td>
<td>Correlation coefficient</td>
</tr>
<tr>
<td>Teaching approach</td>
<td>0.99 (0.70-1.21)</td>
<td>0.79</td>
</tr>
<tr>
<td>Course design</td>
<td>0.59 (0.34-0.84)</td>
<td>0.65</td>
</tr>
<tr>
<td>Course content</td>
<td>0.85 (0.51-1.20)</td>
<td>0.68</td>
</tr>
<tr>
<td>Inspire students</td>
<td>0.80 (0.32-1.27)</td>
<td>0.52</td>
</tr>
</tbody>
</table>

### Table 3 Con’t

<table>
<thead>
<tr>
<th>Variables</th>
<th>Student social and cultural experience</th>
<th>Regression coefficient (95% CI)</th>
<th>Correlation coefficient</th>
<th>P value</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching approach</td>
<td>0.67 (0.14-1.19)</td>
<td>0.43</td>
<td>0.01</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>Course design</td>
<td>0.28 (-0.19-0.74)</td>
<td>0.21</td>
<td>0.28</td>
<td>4 %</td>
<td></td>
</tr>
<tr>
<td>Course content</td>
<td>0.68 (0.05-1.31)</td>
<td>0.37</td>
<td>0.04</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Inspire students</td>
<td>0.02 (-0.78-0.82)</td>
<td>0.01</td>
<td>0.97</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Note. P < 0.05 shows the statistically significant result.
As shown in the table above, all aspects of STLE approach including the critical reflection teaching method, problem based course design, research based course content, and methods to inspire student’s learning, are significantly associated with students critical thinking and increasing students capacity to undertake research. This is in comparison with the low level to non-significant relationship between each of the STLE four scales and student social interaction in this course.

The qualitative data provides further evidence that students felt the approach significantly facilitated their critical thinking:

- ‘I think the approaches that are used are good. I’m probably more inquisitive now about how to do things and I approach things from a different angle now that I have a more thorough understanding of what to do in research and especially quantitative research. What I think also that going to the encouraging of student engagement, the other students in our course, there’s very varied backgrounds in our course, so that’s very interesting and also she opens up the class to discussion. So people within the class are all working on their own research projects, so they all relate things that we are taught to their projects. In turn, then put questions forward. So it’s very interesting. It was an engaging class, lots of students participated because everyone was really inquisitive about the topic’.

- ‘For me the approaches used in the quantitative research were very helpful for me to learn the knowledge of the skills of quantitative research, also I try to link this knowledge and the skills into a research project which I plan to do in the future’.

- ‘So in that way it's been really good, and I think it is definitely helping develop the critical thinking’.

Reflection from qualitative data also shows that the STLE approach significantly enhanced students learning and improve their study and research skills.

- ‘Oh definitely yes. As I just said, I didn’t had any background in research before I took this course. And of course my research skills have been improved a lot. Now I can read any paper or report and I can judge it. I can criticise it, I can have a say in the meetings, as I said, the validity, the reliability of the results...So, yes, that was really good’.

- ‘Yes, it has tremendously improved my research skills. Firstly, it's given me the confidence to be able to analyse things easily. It's also given me a clear understanding of quantitative research and the ability to put together a clear and concise plan of how I'm going to address something. It really has helped me so much because I use the skills that I've learned every day’.

- ‘I believe it does improve my research skills. Before the course I knew nothing about quantitative research because I'm not from the researching background at all. So if I want to do a quantitative research project, I know how to design my research and how to collect data, how to analyse the data. So I think it is really effective in term of me enhancing my research skills’.

- ‘Because I learn and also practice at the same time. So I think it’s very beneficial for me’.

3 DISCUSSION AND CONCLUSIONS

The present data suggest that STLE did support a general increase in critically statistical thinking in postgraduate students and enhanced their learning. It was found that use of reflective teaching methods, problems based course design, and research based course content significantly improved to student critical thinking and enhanced their learning and research skills development. As mentioned in an earlier section, most health related discipline students in Honours and postgraduate coursework programs at this University take this particular statistics course. The course design and course contents are specific to their research degree, postgraduate research projects and course study, and deal more with the relevant aspect of personal research and quantitative skills. It is suggested here that students critical thinking has been significantly enhanced through these problem based and research based statistics learning.

In comparison with the high level of relationship between STLE approach and student critical thinking development, the relationships between four scale of STLE approach and social interaction in students are low. This may be because the statistical learning occurs in statistical context and
environment, rather than through social interaction [1, 2]. This makes sense in terms of cognitive loading. Although there was a sequence of group discussion, followed by discussion to reflect the concepts learning with the facilitator of generated thoughts and ideas, this in fact enables students to focus their mental energies on fulfilling the task and technical part of the study. This may be because the discussion and group activities focused on facilitating task oriented critical thinking process but not enhancing social interaction [10].

The highly significant association between critical reflective teaching method and problem based course design, and research based course content suggest that the application of critical reflective teaching methods needs to combine with the presentation of problems and research based course content into the teaching. Jonassen [7] suggested that student thinking was initiated by research problems, followed by discussion to reflect the problems; It has been suggested that from the current study that presentation of research problems, discussions and reflection consists of a learning continuum to lead to critical thinking and thoughtful actions in quantitative research. The study confirmed that the STLE approach was able to enable student construct meaning about statistical concepts and analytical methods based on their experiences. This occurred through developing students central statistical ideas, using real and motivating data sets to engage students in making and testing research hypotheses, using classroom activities to support the development of students’ reasoning and critical thinking, integrating the use of statistical softwares that allow students to test their inferences, explore and analyse data, and develop their reasoning and thinking in statistics; promoting classroom discourse to reflect the significant statistical ideas; and finally, incorporating real research datasets into assessment to learn what students know and to monitor the development of their statistical thinking development. In this context the STLE approach is highly effective.

REFERENCES


