Active Learning in Thermal and Statistical Physics at the University of the Witwatersrand

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Abstract. Active learning techniques have been employed in the 2nd and 3rd year Thermal and Statistical Physics modules since 2009. The introduction of these methods has resulted in increased student participation during lectures, and improved student performance in both modules. This paper reports on an ongoing evaluation of active learning initiatives in these two modules, and compares and contrasts student performance in, and attitudes to, modules at 2nd and 3rd year level that are not presented using active learning. The study suggests that active learning has the potential to improve student performance and understanding in higher level courses, and that this approach may benefit experienced physics instructors in teaching concepts that are traditionally regarded as difficult by students.

1. Introduction

Active learning (AL) strategies have the potential to improve student learning, and hence their performance in assignments, tests and examinations in all spheres of education. They include active learning, collaborative learning, and problem-based learning, as well as the provision of regular feedback to the student cohort. Prince [1] has produced an illuminating review of the research on the efficacy of using AL techniques in university teaching. While his conclusions are largely positive, he cautions that empirical evidence for improvement may be less clear-cut than might be hoped and expected. Felder [2] points out that recent result cognitive research provides more convincing evidence that these strategies improve student learning. For example, the book by Ambrose *et al* [3] deals extensively with the processes by which students learn, and the seven strategies they propose for effective or smart learning provide strong support for the implementation of AL.

While the primary focus of research on the use of AL in physics classrooms has been on first year or freshman courses [4], they have been employed in intermediate and upper-level courses [5]. AL strategies in higher level Thermal and Statistical Physics courses has been the subject of recent studies by Loverude [6, 7] and Christensen *et al* [8], where the focus has been on developing and evaluating specific AL materials. Lopez and Gross [9] have applied AL in a graduate Space Weather Modeling summer school, while Wiljhelm *et al* [10] have used AL in teaching the Physics of Medical Imaging.

AL techniques have been employed in the School of Physics at the University of the Witwatersrand (WITS) in the 2nd and 3rd Year Thermal and Statistical Physics modules since 2009. A recent report [11] on the effect of introducing these into the 3rd Year Statistical Physics module has suggested that students have embraced the deployment of these techniques, and that an improvement in student performance has resulted from applying these strategies. This paper reports on several student evaluations of lecturer performance (SELP) surveys, an analysis of student performance over a number of years in the 3rd Year module, and a comparison of student performance in the four components of the Physics II course during 2011. It is concluded that AL has had a positive impact on student attitude and performance, and that AL should be considered by experienced and successful physics lecturers who teach intermediate and advanced level courses. For those that may be interested in trying out these techniques, Felder and Brent [12] provide and engaging and informative short paper on the benefits and potential pitfalls of introducing AL in their lectures.

2. The 2nd and 3rd Year Physics Courses at WITS

2.1. Physics II

The Physics II course is divided into two modules. Both modules have a laboratory component. The PHYS2001 module (taught in the first semester) has two theory components – Classical Mechanics and Modern Physics. PHYS2002 (offered in the second semester) also has two theory components – Electrodynamics and Thermal Physics. Each theory component is presented by a different instructor.

2.2. Physics III

The Physics III course is divided into five modules, one of which is the laboratory module and includes a major project. The other four (theory and lecture-based) modules focus on Quantum Mechanics (PHYS3000), Applications of Quantum Mechanics (PHYS3001), Statistical Physics (PHYS3002) and Waves and Modern Optics (PHYS3003). Each theory module is presented by a different instructor.

3. Details of Active Learning Strategies Employed in Thermal and Statistical Physics

Details of the AL techniques employed during the lectures have been given in a previous paper [11], and it is not necessary to present these in detail here. To recap briefly, these are Lecture Activities and Co-operative Learning, Minute Papers and Responses, Conceptual Questions and Active Tutorials. In addition to these strategies students are provided with regular set assignments which contribute to their final mark, and one test and one examination form the bulk of the final mark for the module. It is important to note that students were explicitly told that AL techniques were being employed, and that their use was based on substantive and convincing education research.

4. SELP Surveys

Regular SELP surveys have been administered in the Statistical Physics module of Physics III. The multiple response evaluation employed is the standard Strongly Agree (10), Agree (7.5), Neutral (5), and Disagree (2.5), Strongly Disagree (0) scoring method. In order to make sense of the data provided in Table 1, it is necessary to provide some background to the manner in which the course was taught in the three years surveyed. In 2005 the course was taught using the traditional ‘chalk-and-talk’ method, as opposed to more modern trend of using a computer-generated presentation and data projector. This was the first time the author had taught the course, but student reaction was largely positive. AL was introduced in 2009, and the two surveys from 2009 and 2012 show a marked improvement in several key factors. It is interesting to note that efforts to engage the students in discussion (‘Lecturer encourages audience participation’) were recognized by the student cohort of 2005. While the 2012 class appear, as a collective, to be less comfortable about participating in class discussions, the lower score appears to have been the result of two students who felt strongly on the matter. The 2012 class were the first group surveyed who had also been taught using AL in their 2nd Year. Comments received in the open-ended questions in both the 2009 and 2012 surveys indicated that the students have collectively and individually given their approval to AL. Examples from the 2009 survey include the following:

- The minute papers are a very nice addition. It is really nice to have a lecturer that clearly puts so much effort in. Thanks.

- I found the activities really good; you learn while you do them and can't go lazy on your attention. They made lectures more enjoyable. I also looked forward to the tut sessions, and the minute paper responses are appreciated.

Similar comments came from the 2012 survey, some of which suggested possible improvements to the course:

- The minute papers and lecture activities have been pivotal to my understanding of the course material. Going through the tutorials myself has always added value to my understanding. Minute papers help clarify points which were unclear in the previous lecture.
- Assign a roster for the active tutorials rather than asking for volunteers as it can be intimidating when you call for volunteers and no-one is willing to stick their neck out.
- The most valuable part of the course is the lecture activities, because they give us the chance to apply the concepts immediately. I think this helps us retain the information presented longer.

Table 1. A comparison of three Student Assessment of Lecturer Performance surveys undertaken over the period during which the Statistical Physics III module has been lectured by the author. Active Learning was introduced during 2009.

Assertion	Score		
	2005	2009	2012
Lecturer makes the purpose of the lecture clear	9.32	9.29	8.75
Lecturer stimulates interest in the subject	8.86	9.11	9.38
Lecturer is always well-prepared for class	9.09	10.00	9.84
Lecturer is available for consultation	8.18	9.29	9.06
Lecturer encourages audience participation	10.00	9.29	9.69
Lecturer communicates effectively	9.09	8.93	9.38
Lecturer chooses and organizes material well	7.95	8.93	9.53
Lecturer pitches lectures at an appropriate level	9.32	9.11	8.92
I gained a good understanding of concepts and principles	7.73	8.58	8.14
I was motivated to do extra work	7.50	8.04	8.30
I feel comfortable about participating actively in class	8.18	8.58	7.84
The lecturer welcomes independent thinking	8.86	8.93	9.06
The lecturer is approachable for individual questions	9.09	9.65	9.08
The lecturer has enthusiasm for the subject	8.64	9.83	9.69
Instructions and assessment criteria are clear and specific	8.41	9.29	9.06
Lecturer makes digressions which add interest	7.27	9.47	8.28
Lecturer links the lecture to other parts of the course	9.32	9.47	9.06
Lecturer summarizes the main points effectively	9.09	8.93	9.69
Lecturer gets feedback on student understanding	8.86	9.65	9.69
Lecturer's grasp of my level of knowledge is realistic	8.41	8.40	8.28
Lecturer is clear and understandable in his explanations	8.41	9.11	9.06
Lecturer shows thorough knowledge of his subject	8.64	9.47	10.00
Average Score	8.65	9.15	9.08

The 2012 survey included an additional section designed to probe student reaction to specific AL strategies, impressions of the assessment of the assignments, and student use of the on-line resources provided on the course website that was developed and introduced in 2012. The results of this section of the survey are presented in Table 2. While student reaction to the minute papers and lecture activities are overwhelmingly positive, the active tutorials are less popular (as may be expected from the small selection of student responses noted above). Use of the course website and the on-line textbook [13] was disappointing, but the students obviously regard the website as a vital component of their learning experience. It should be noted that the on-line textbook has been used as the primary reference text by the students since 2005, and that the two courses are structured with this textbook in mind.

Table 2. The results of a student survey administered in March 2012 designed to probe student attitudes to specific active learning initiatives, and to gauge use of the course website, and the on-line textbook used for the course. The results of the survey are discussed in the text.

Assertion	Score
Assignments were marked fairly and returned promptly	9.84
Minute Papers are a valuable part of the course	9.53
I use the Minute Papers to highlight difficult material	9.06
Lecture Activities are a valuable part of the course	10.00
Lecture Activities help to develop problem solving skills	9.38
I like the Active Tutorial sessions	7.50
I use the course website regularly	7.20
The course website is a valuable resource	8.77
I have used the on-line textbook of the course website	5.03
The on-line textbook is relevant to the course	6.89

5. Comparison of Student Performance – with and without Active Learning

As Prince [1] has pointed out, a full endorsement of AL requires empirical evidence that student performance has significantly improved as a result of their implementation. In this section an analysis of student performance in courses taught with and without AL is presented.

Table 3. Performance of the students in 3rd Year Statistical Physics over a period of eight years. The same lecturer has taught the module in each of these years. Active learning was introduced in 2009, and student performance has significantly improved from 2009 onwards.

Year	Exam Average (%)	Final Average (%)	Pass Rate (%)
2005	60	62	71
2006	58	62	94
2007	56	59	71
2008	64	65	93
2009	76	75	100
2010	73	74	100
2011	74	75	84
2012	79	81	94

Student performance in the Statistical Physics module over a period of eight years is summarized in Table 3. In the years 2005-2008 the course did not include AL methods. The data presented show a dramatic increase in both the exam performance, and in the final mark for the module. These results are statistically significant, and provide concrete evidence that AL improves both continual assessment, and retention of the course material under exam conditions. While it may be argued that improved performance may be the result of the instructor becoming more competent, this is countered by the excellent results of the 2005 SELP. An identical analysis of the 2nd Year Thermal Physics results over a shorter period shows a similar dramatic improvement in student performance when the course component was presented using AL.

Table 4. A comparison of the general student performance in Physics II by course component during 2011. It is clear that Thermal Physics is the only component in which student performance in the Exam and in other activities is comparable. While the connection between active learning and student performance is clear, there are other factors involved. These are discussed in the text.

	Component A		Component B		Component C		Thermal Physics	
	Exam	Class Record	Exam	Class Record	Exam	Class Record	Exam	Class Record
Average (%)	40	65	39	58	41	75	68	73
Pass Rate (%)	34	75	28	50	36	88	84	89

A comparison of student performance in 2nd Year Physics during 2011 over the four components is presented in Table 4. Before proceeding with an analysis of the data presented it is important to take cognizance of the following observations. Components A and C are more demanding of the students mathematical skills, and student performance in these topics has traditionally been poorer than that in Thermal Physics, which may be considered as less demanding. The class record performance in Component C is excellent, and this is probably due to the progressive continuous assessment policy of the lecturer concerned. In addition, Components A and B are examined during the same exam, as are Component C and Thermal Physics. Students therefore have the option of spending more time on "easy" material during the exam. It is clear, even when taking these considerations into account, that the exam and class record performance is comparable in the Thermal Physics component, while exam performance is significantly lower in the other three components. This is strong evidence that students are retaining the material presented in the Thermal Physics lectures more effectively than they do in the other components, and is arguably further empirical evidence that the implementation of AL raises student marks in a statistically significant manner. A similar comparison of student performance in the modules of the 3rd Year Physics course shows that the Statistical Physics module has, on average, a better correlation between exam and class record performance, and that the students consistently perform better in this module than they do in the other three theory based modules.

Finally, the analysis of individual results for students over all years and for both modules provides some additional relevant insights. The most capable students over the years have consistently obtained marks in excess of 90 %, with the best mark usually being in excess of 95 %. It would appear that these students have the ability and motivation to perform exceptionally whatever strategies the lecturer employs. It is the students in the mid-range who appear to benefit most from AL, and it is these students that boost the overall class performance. It is perhaps obvious, but nevertheless worth noting that the small number of students who fail the course after the introduction of AL are students who do not attend the lectures.

6. Conclusions

Active learning (AL) techniques are now well-established in the 2nd and 3rd Year Thermal and Statistical Physics modules presented at WITS. It has been shown that these techniques have been accepted with noticeable enthusiasm by the students taking these courses, and that student surveys show that the students have recognized that the techniques have improved the lecture room experience. It is interesting that the student response in open-ended responses echo the opinion of those involved in educational research as to why these techniques result in effective learning.

A comparison of student performance in the Statistical Physics module, over a number of years, provides statistically significant evidence that AL improves student performance in this particular module. It would appear that all students benefit from AL, particularly students in the mid-range of performance, while it is clear that those who do not attend lectures are invariably those that prove to be at risk of failing the modules.

A comparison of student performance in the different course components across the 2^{nd} Year of study in 2011 provides compelling evidence that students retain the presented material more effectively when AL methods are used extensively, although it is recognized that other factors certainly play a role in student performance.

This study suggests that experienced physics instructors who are responsible for intermediate and advanced level courses should consider employing AL techniques in their lectures. In addition to the obvious benefit of providing students with an improved service, the employment of AL (particularly the use of minute papers) allows the instructor to reflect immediately on whether important points are recognized by the students, and what material the students are having difficulty comprehending.

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