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Managing Active Learning Processes in Large First Year Physics Classes: The Advantages of an Integrated Approach

ABSTRACT

Turning lectures into interactive, student-led question and answer sessions is known to increase learning, but enabling interaction in a large class seems an insurmountable task. This can discourage adoption of this new approach – who has time to individualize responses, address questions from over 200 students and encourage active participation in class? An approach adopted by a teaching team in large first-year classes at a research-intensive university appears to provide a means to do so. We describe the implementation of active learning strategies in a large first-year undergraduate physics unit of study, replacing traditional, content-heavy lectures with an integrated approach to question-driven learning. A key feature of our approach is that it facilitates intensive in-class discussions by requiring students to engage in preparatory reading and answer short written quizzes before every class. The lecturer uses software to rapidly analyze the student responses and identify the main issues faced by the students before the start of each class. We report the success of the integration of student preparation with this analysis and feedback framework, and the impact on the in-class discussions. We also address some of the difficulties commonly experienced by staff preparing for active learning classes.

KEYWORDS

active learning, science education, learning outcomes, first year experience

INTRODUCTION

Imagine a large first-year physics class: first lecture, first semester. Bright-eyed, excited, attentive; a sea of eager faces wait, bristling with anticipation for the great wisdom that will surely expand their minds to a cosmos of possibilities. However, by Week 3, many of these students need to be woken up, having been lulled into the stupor caused by content-rich, activity-poor hours of lecturing, much to the chagrin of the lecturer who has labored long into the night preparing “killer” lectures.

Chickering and Gamson in their seminal 1987 work suggest that students must do more than just listen: they must read, write, discuss, and be engaged in solving problems (Chickering & Gamson, 1987). Most important, to be actively involved, students must engage in such higher-order thinking tasks as analysis, synthesis, and evaluation. Active learning can be described as "any instructional method that engages students in the learning process" (Prince, 2004, p.1) and has been increasingly adopted as an approach to support student learning in higher education (Bonwell & Eison, 1991).

The advantages of various forms of active learning approaches to undergraduate university teaching, especially compared to traditional lectures, are well documented (e.g. Deslauriers, Schelew, & Wieman, 2011; Hake, 1998; Kuh, 2008; Prince, 2004). According to these theorists, active learning ideally consists of personalized feedback; pre-reading and preparation; motivation and relevance; immediacy in response from lecturer; collaborative learning; provision of just in time feedback, formative assessment; personal response from and engagement with academics: in essence, student-centered learning (Kuh, Kinzie, Cruce, Shoup, & Gonyea, 2006; Sokoloff & Thornton, 1997; Trowbridge & McDermott, 1981). Interaction between students and faculty staff and active learning processes has been noted in particular to offer higher levels of student engagement, as do one-to-one interaction within the lecture theatre and whole class discussions (Kuh, Kinzie, Schuh, & Whitt, 2010; Meltzer & Manivannan, 2002; Meltzer & Thornton, 2012).

This stress on student-centered learning is, however, sometimes difficult to achieve in large class situations and is less likely to occur in a traditional lecture theatre where room layout can stymie attempts to encourage interactive learning.

The massification of higher education in general means that core knowledge and skills still need to be acquired by students, but on a much larger scale. The measures imposed by institutional policy-makers to cope with massification–the move from small tutorial-style classes and classrooms to large, tiered lecture rooms; the provision of service teaching for different degree programs in the same unit of study, and the increased use of educational technologies–can all work against effective learning (see, for example, Barr & Tagg, 1995, Gibbs, Lucas & Simonite, 1996, Bruffee, 1999, and Harris & Cullen, 2010). The challenge to teaching staff is greater still if these occur at the same time as reduction in staff support, a reduction in the number of contact hours per semester and increased administrative demands for quality assurance and accountability (Gappa, Austin, & Trice, 2007).

Various strategies have been developed by practitioners to address the challenges of encouraging active learning in large classes. For example, Beatty, Leonard, Gerace and Dufresne use a technique they call "question-driven instruction" in which the posing and discussion of conceptual questions dominate class time (see Beatty, Leonard, Gerace & Dufresne, 2006b). An early form of this approach was the "Peer Instruction" model by Mazur (1997). Mazur described a mixture of short presentations and questions, but the major emphasis of Peer Instruction is that students discuss conceptual questions with each other in class and teach each other in the process. A closely-related approach is the "SCALE-UP" interactive laboratory environment (Beichner, 2007), where students solve problems together with minimal "lecture" time.

The difficulties experienced with implementing active learning revolve around the issues of managing the process. While audience response systems, commonly known as "clickers", have been described as effective tools to manage strategies which engage large groups of students (Caldwell, 2007), there are limitations to their use. Beatty, Gerace, Leonard, and Dufresne (2006a) present a detailed strategy for the design of effective questions, but recognize that this is a "challenging and time-consuming" task that can discourage adoption of the approach. They also stress that question design is only one component of the approach and that how the questions are used in class is more important. Kay and LeSage (2009) list three specific challenges for lecturers using clickers. The first issue is that it is difficult (especially for less experienced teachers) to respond immediately to the student feedback provided by the responses, especially when unexpected misconceptions are revealed. The second concern is that less material can be covered in this type of class. They mention the option that requiring students to do more preparation outside the class could address this. Finally, similar to Beatty et al. (2006a), they stress that designing good questions "can be a demanding task for instructors", (Kay & LeSage, 2009, p.6) noting the lack of existing material to draw upon. Kay and LeSage also discuss challenges for students arising from this approach. The students are certainly required to participate more in active learning classes, and the discussions do not always run smoothly. Some students dislike having their responses used for summative assessment. None of these are noted as major problems, although relatively little data were available to quantify the student views.

In this paper we describe a specific, integrated approach to active learning that supports the class activities with extensive preparation by both the teacher and the students. A key feature of our approach is the rich data it provides to teachers about student understanding before the start of each class. This approach also addresses some of the common challenges experienced by teachers using an active learning approach in large first year classes. We present the results of a mixed methods evaluation approach (Greene, 2007), describing how this teaching model works in practice for the students and their learning, yet is still manageable for teaching staff. The particular approach we describe has been heavily influenced by the work of Eric Mazur (1997), Bob Beichner (2007), and the University of Colorado Physics Education Group (e.g. Pollock, 2009).

AN INTEGRATED APPROACH TO MANAGING ACTIVE LEARNING

Introduction to physics for first-year undergraduate students at this research-intensive institution occurs across two units of study. Each year is divided into two semesters of 13-weeks: each unit runs for one semester. The class sizes range from 200 to 300 students, the majority taking a Bachelor of Science degree, the remainder being engineering students. The lecture is the primary contact point for teaching. There are laboratory or practical sessions in which students are expected to perform experiments, communicate the results to others and deal with uncertainties in the measurements. Students are further supported with tutorial sessions providing assistance for problem sets. The first unit is co-taught by two lecturers and the second unit by three lecturers. The second unit is taught twice a year to accommodate additional engineering students who do not take the first unit. A total of 7 staff lectured in the two units during the period of this study.

Our interactive teaching approach was initially developed for just the first unit of introductory physics. The work described in this paper was funded by a small internal grant to support the evaluation of the existing program and the development of software to scale the approach to larger class sizes. This allowed us to adopt the approach in the larger classes of the second unit of introductory physics.

The active learning approach discussed here has two distinctive phases: (1) pre-class preparation and (2) in-class active learning. The shift in focus to pre-class preparation has been complemented by a de-emphasis on "covering content" in the lectures (the traditional approach in this subject). Rather than the lecture being a teacher-led oration, the lecturer makes sure that any core concepts that the students found difficult are discussed in detail, but shifts the onus of "coverage" to students to read and study outside class. The focus of the class session is then a series of discussions of each of the core concepts for the lecture as defined by the learning goals for the unit of study, effectively turning the lecture into a mass tutorial experience. This approach is a new experience for most students, so we motivate them in the first lecture, notably by presenting evidence of the increased learning gains obtained by active learning.

Pre-class activities

The steps employed to prepare the students and the lecturers for each class are summarized in Table 1 and explored further below. The focus of the pre-class stage is always a short online written quiz that the students must submit before each lecture, based on their assigned reading preparation.

These pre-reading exercises form part of the overall assessment, worth 5 percent of the total for the unit. Marks are awarded for effort rather than correct completion of the questions. Full marks are, therefore, awarded if the students answered all questions seriously, regardless of how many are answered correctly.

The first two of three questions of each quiz are conceptual and interpretive questions based on the key concepts identified for each reading. The final question always asks the students what they found hardest in this reading (Angelo & Cross, 1993; Crouch & Mazur, 2001). This question was designed to pick out the common problems experienced by the students and is posed in the format described by Crouch & Mazur.

The completion deadline for the online quiz is set less than 12 hours before the relevant lecture. This means the lecturer must process the quiz responses very rapidly ahead of class to identify common difficulties requiring discussion; a complex task as written answers are used rather than a multiple-choice quiz. Initial management methods were to simply scan the responses to the final question to establish an efficient, overview summary of key issues (Crouch & Mazur, 2001). To improve this process, we developed a purpose-built computer software tool that extracts and consolidates the responses from the web-based-courseware.[1] Using a thematic analysis algorithm (Lee & Seung, 1999), the software automatically selects the three most common themes and ranks each student comment against each theme. The ranking allows the lecturer to quickly find comments that strongly encapsulate each theme.

When the student comments and themes address the core learning objectives for the lecture or describe important difficulties, the lecturer includes these into lecture slides in preference to other stock examples. This approach allows the lecturer to use different or modified concept questions in the lecture that more closely examine any misconceptions revealed by the student comments. The slides are often modified to include at least one de-identified student comment relating to each topic of difficulty.

Students often use the final quiz question to raise more general issues, not simply those related to the required reading, sometimes including particularly notable comments or important questions. The software tool allows the lecturer to efficiently respond by

Table 1: Sequence of pre-class activities

1. Instruction	The lecturer assigns a section of the textbook to read for each lecture, and sends an email to all students listing the most important concepts for each lecture. *For a class on circular motion, the concepts were described as:* • *The idea of "centrifugal force" as fictitious force acting in a non-inertial reference frame.* • *Vertical circular motion in the presence of gravity – why the water stays in the bucket. The varying combination of e.g. normal + tension force.*
2. Student preparation	Students complete an online short written-answer quiz based on the readings before the lecture.
3. Feedback	If any student makes a particularly notable comment, the lecturer uses the software to reply to them by email.
4. Assessment and analysis	The lecturer uses computer software to rapidly mark the quizzes, identify common difficulties, and select responses for discussion in class. *The themes identified from the student responses for the class above were:* • *Centrifugal force* • *Gravity on a rotating Earth* • *Non-uniform circular motion* *The first and third of these matched the learning objectives and were selected for class discussion.*
5. Lecturer response	The lecturer copies selected de-identified student comments into the lecture slides including examples of good answers and those demonstrating misconceptions. *The software gave the following two student responses a high match to the first theme. Both clearly identify the problem but the second also reveals the thought process behind a misconception.* • *"The idea that centrifugal force isn't really a force at all. It feels as such, but there are only centripetal forces"* • *"The most difficult section in this section of the reading is the idea that centrifugal force does not actually exist in inertial reference frame. From high school, we learn that <u>centripetal force and centrifugal force always exist together</u>"* (emphasis added).

email through a single button operation, which addresses and composes a template email response to that particular student, including a quotation of their answer.

Active learning in class

The students are led to participate in class discussions as described in Table 2. Each discussion starts with one or more of the students' quiz responses to illustrate why the concept is difficult to them. The lecturer has the students work on a series of conceptual questions designed to build and test their understanding. Students do so in an approach strongly modeled on Mazur's "Peer Instruction" model (Mazur, 1997), with multiple-choice questions answered anonymously using clickers. The responses are captured on the lecturer's computer, displaying the percentage of students choosing each answer option. Each question is normally asked twice, the first as an individual response. The results of the first question are recorded by the lecturer but not shown to the students to avoid giving any clues.

All the students in the class are then invited to discuss their answers with their neighbors to try and convince each other of the correct answer. After discussion, the students answer a second time, and the distribution of their answers is shown to the class. Follow-

Table 2: Sequence of in-class activities

1. Feedback		Selected student comments are displayed before the lecture starts to illustrate any general problems.
2. Instruction		Any general student-raised issues are addressed/explained by the instructor.
3. Core learning objective discussion (repeated)	a) Instruction	Some very brief summary material may be presented to motivate the topic.
	b) Feedback	Selected student comments are displayed to illustrate the common difficulties.
	c) Student response 1 (personal)	Students answer a concept question individually (with no discussion) using an electronic response device. The instructor views a bar graph of the student responses. This is not shown to the class.
	d) Student peer instruction	Students discuss their answers with their neighbors to convince each other of the right answer. The instructor moves around the class to monitor and assist the discussions.
	e) Student response 2 (with peers)	Students answer the same question after discussion. The bar graph of answers—after discussion—is revealed.
	f) Student peer instruction	Several students are asked to explain why they chose a particular answer.
	g) Feedback	The correct answer is revealed, with an explanation from the instructor if necessary.

ing this we invite a few students to explain how they chose a particular response, aiming to get multiple points of view that will stimulate discussion. The lecturer moves around the room with a second microphone at this stage to solicit input from as many different students as possible. This is very important as a means to illustrate the process of problem solving. It often reveals further problems in the approaches used by the students that the lecturer can then address. At the end of the discussion, the lecturer summarizes the argument for the correct answer to reinforce the concept.

In a few cases with a more challenging question, typically probing a strong misconception, the majority vote is still not for the correct answer. The lecturer may then intervene to explain the concept.

We do not rely solely on the multiple-choice questions for student activities. We also ask students to work in groups on simple problems, or to draw graphs together on paper. The lecturer inspects the work of a few groups to identify problems before leading a class discussion on the activity.

MEASURING IMPACT OF THE APPROACH

The evaluation strategy adopted a mixed methods approach (Creswell & Plano Clark, 2007; Greene, 2007) to understand the impact of the approach on student engagement and student learning. Drawing on multiple data sources, an evaluation team external to the teaching team conducted the analysis. No identified student data were disclosed to the teaching team members. The University Ethics Committee approved our procedures before we conducted any data collection activities (Ethics no. 2011000428). The evaluation strategy was piloted in 2011 and the data presented here are drawn from the evaluation conducted in 2012.

Methods

Four main methods were used to collect data: (1) pre- and post-instruction testing of students; (2) observations of in-class activities; (3) summary data from responses to the in-class questions; and (4) student focus groups. We summarize each of these methods in this section, followed by a brief discussion of the limitations of our methods.

Pre- and post-instruction testing

The student learning gains were measured with pre- and post-instruction testing using standard benchmark tests. We used the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) and the Brief Electricity and Magnetism Assessment (Chabay & Sherwood 1997). The pre-instruction test was given in the first week of semester and the post-instruction test was administered as the mid-semester exam. Both tests were given to all students in the same room as normal lectures, in the same conditions. Normalized gain measures were used to determine what fraction of the concepts *not* understood in the first test was understood in the second test (after Hake, 1998).

Observation of in-class activities

Two independent evaluators observed lectures for both units. The lecture observations were conducted during the 11 AM class in general lecture theatres and ran for 50 minutes. Two different lecturers, one experienced in the approach and the other a new adopter, led the classes. An observation guide was used to capture observations. The observers met prior to the observations to agree on the method of recording and used the same observation form for all observations. Both observers carried out analysis of the observational data to improve consistency and reliability.

Summary data from in-class clicker questions

In one of the units we recorded the percentage of correct responses to the in-class clicker questions before and after the peer instruction discussions (see Table 2). For each posing of a question the lecturer recorded the percentage of responses with the correct answer directly from the computer display, with the aim of determining what learning took place during the peer instruction phase. Some 90 percent of all questions were recorded in this way.

Student focus groups

A total of 11 students, six males and five females, from the two classes volunteered to take part in two focus groups conducted at lunchtime during Week 10 of the semester. Four students were in their first year of study, post high school; one was in his third year of study and one was returning as a mature age student.

Facilitated by an independent investigator, the focus groups ran for one hour and were conducted using a semi-structured questioning technique. A thematic analysis of the recordings of the focus groups was conducted.

Limitations of our methods

Much of our data was necessarily qualitative in nature: the in-class observations and focus groups in particular, but also the anecdotal reports from students and staff. This was sufficient for our main aim, which was a formative evaluation of our new teaching approach to drive the development and adoption process. However, it became apparent from the focus groups that there was a problem with the pre-class reading taking much longer than expected (see *Student Engagement* section), although we had not obtained any data about this. Ideally we would objectively measure the time taken by students for the reading preparation. More generally, in any future study we would compare the effectiveness of different activities by measuring the increase in student understanding at each step through the process of pre-reading, class discussion, and homework activities.

Analysis

The test results and the themes developed from the focus groups and observation data were analyzed to explore the impact of the approach on (1) student learning outcomes; (2) student engagement; (3) teaching preparation by staff; and (4) managing change from the lecturer's view.

Student learning outcomes

The students in our study obtained very strong learning outcomes as measured by standard benchmark tests. In the first unit the mean normalized gain of the class was 58 percent (for 154 students) measured by the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992). For comparison, traditional classes typically obtain gains of 23 percent and interactive classes achieve gains of 48 percent (Hake, 1998). We split the student results into two samples according to the median pre-instruction score (17 out of 30). The stronger half of the class (score greater than 17 out of 30) had significantly higher gains than the weaker half of the class (72 percent compared to 52 percent, p=0.004). Beichner et al. (2007) obtained similar results, suggesting that the stronger students benefit more as they are conducting the (peer) instruction in class.

In the second unit we tested the students after instruction using the Brief Electricity and Magnetism Assessment (Chabay & Sherwood 1997). We obtained a mean normalized gain of 47 percent. In comparison, traditional first-year university classes obtain average gains of 23 percent and classes with a concept-focused curriculum report average gains of 42 percent (Kohlmyer et al., 2009).

Student engagement

Increasing student engagement and conceptual understanding within the lecture are primary considerations for the introduction of pre-reading tasks and quiz activities prior to the lecture (Crouch & Mazur, 2001). We found that students approached the pre-reading tasks in a number of different ways: some students were "skimmers", completing enough reading to be able to provide coherent answers to the online quiz; others read through the material methodically, took a series of notes, completed exercises in the book and then completed the online quiz. A third of the group preferred to read the material and relate it to past experiences and then complete the online quiz.

A common concern raised by some teachers and students is that this form of lecturing does not cover as much content as traditional lectures. This is certainly true, but that is no longer the aim of the class time. It is the responsibility of the students to cover the material in their own reading time and use class time to test and extend their conceptual understanding of the key material. Students appear to have accepted that responsibility and are sufficiently motivated to do the pre-readings and associated quizzes. The quizzes have a mean completion rate of 63 percent (median 83 percent). Feedback from students in the surveys and focus groups suggests that this motivation is supported by the strategy of providing marks, and individualized and lecture-based responses to students' responses to the quizzes.

The students clearly indicated that the reading takes significantly more time than envisaged by the lecturers. This issue needs further investigation. The time required by an average student to adequately study the full content of the unit of study may not be consistent with the nominal allocation at this university of 10 hours per unit of study per week including all class contact time.

The in-class clicker response data indicate that peer instruction has a positive impact on student understanding as the fraction of correct answers significantly increases between the individual responses and the discussion session. In the first unit, the average percentage of correct answers increased from 55 percent to 67 percent (N=76 questions, T-test $p<0.001$). Observations of classes by external evaluators noted active discussion, with students often arguing and using persuasive body language as well as gesturing, mimicking forces in diagrams displayed on lecture slides.

Focus group participants were in general agreement regarding the value of "clicker" questions and the emphasis given to the opportunities for both instant and delayed feedback. Students valued the chance to revisit the problem and the discussion that ensued.

The nature of the active learning process allows for students to interact with each other in the lecture theatre. Having been exposed to a number of teaching methods in their short time at the university, students who attended the focus group sessions were clear about what was working for them. *"Eight people on Facebook, three guys on YouTube and 13 people asleep in [another unit of study], that's why I love the Physics lectures because they're actually good fun . . ."*

Students who have the answer can provide support to those who have yet to reach understanding: the aim of peer instruction (Mazur 1997). Students pointed out how valuable it was when the majority got an answer wrong and so the lecturer could intervene to address their misunderstanding. This was particularly true when they had been very confident of the wrong answer: *"That's when I learn the most. That is revolutionary."* The discussions also demonstrated peer instruction in action—as they were helped by other students (*"If a student explains I get it better"*) or were doing the helping *("The best way to learn is to teach someone else").*

However, there was a suggestion in the student data that the practice of being "strongly encouraged" or "made to" sit with other students was not always welcome and that the forced nature of the group discussion engendered negative feelings for some respondents. However, some students were very positive about this aspect of the lecture, to the point where they reported that they continued to discuss the material after leaving the lecture hall.

The pre-reading online quiz gives students an opportunity to ask questions and to indicate areas of weakness in an environment that offers feedback from the lecturer via either immediate email or during lectures. For the lecturer, the quiz also provides valuable insight into the students' understanding of the material and offers an opportunity to tailor the next lecture to fit the needs of the students.

The in-class clicker questions also offer the lecturer the chance to determine within a short timeframe the level of understanding in the group and to be responsive to that understanding. Observation of in-class activities showed that if there is little understanding, the work on the concept problem went on somewhat longer or if there was general understanding the lecturer moved on to the next idea.

The students value feedback from the lecturers very highly, notably the use of their responses in class. They report much more ownership of issues in class when they see their own words on the screen: "*It proves that it is real.*" Having the difficulty expressed in the students' own words gives the best possible understanding of their point of view, as well as giving the class that same benefit. This strategy also allows lecturers to assess and address changes in the cohort from year to year over time. The difficulties identified by the students do not change greatly from year to year, but there is a real power in our ability to display the problem expressed in their own words.

The positive feedback from the students we observed was strongly supported by the standard course evaluation surveys. Our first unit was ranked among the highest first-year science courses for both overall student satisfaction, and for the amount of "helpful feedback" received by students.

Teaching preparation

A very common issue in teaching is the difficulty that expert staff can have in grasping the lack of understanding experienced by many of their students. One term for this is the "expert blind spot" described by Wiggins & McTighe (2005) in the context of barriers preventing students from developing deep understanding. Our integrated approach provides staff with multiple opportunities to be informed about student understanding.

The main feedback to staff is from the pre-reading quizzes completed by the students before each lecture. These allow the students to express their difficulties with the key concepts in their own words, so the staff know what the problems are before each lecture. The teaching staff found this extremely useful: "*It's a completely different activity when you walk into the room knowing exactly where the students are in their own words – in a normal class you often don't find out until you mark the final exam!*" However some staff also noted that the difficult issues tended not to change much over time: "*. . . once you know what it is once, it doesn't change much from year to year. But it is interesting for the first time to see what they do and do not understand.*"

This feedback continues in class. The conceptual questions are designed to test understanding of the key concepts for each class and make it immediately apparent to the lecturer when students fail to master a concept. The lecturers report that the anonymous nature of the responses gives more reliable data: "*I prefer the active learning method, particularly when the student results are anonymous. It gives immediate feedback of concepts the students are having difficulties with, and allows me to address it on the spot.*"

Managing change

The teaching staff of the two units in our study initially had a range of opinions about active learning, ranging from enthusiastic adopters to some who were not yet fully convinced. (There were none with strongly negative opinions.) We found that an important process to motivate all the teaching staff was to present the results of the pilot study evaluating the first unit. The staff found the data indicating strong learning outcomes and strong student engagement very convincing. Several staff were also motivated by visiting experts: *"I was originally convinced by a series of talks by visiting experts showing data measuring much better learning outcomes."* After a few years of experience all the staff now report a strong preference for active learning approaches: *"By contrast, in active learning the entire class is fully engaged for the whole lecture, since they are expected to actually think and respond in lectures. Where I find the traditional classroom a sterile experience where the lecturer imparts knowledge on the students; the active classroom is dynamic and driven as much by student responses and questions as the lecturer."*

Even among enthusiastic adopters of this approach, we found there were several practical issues associated with the implementation that are worth discussing.

A common concern raised by our colleagues is that this approach needs more time to prepare than normal lecturing. While time is certainly required initially to design good concept questions, overall, the lecturing team found the workload drops, typically by a factor of 2 in preparation time compared to conventional lectures. (The team reported an average of 4.5 hours for the first time an active-learning lecture was prepared compared to 9 hours for a conventional first-time lecture.) There were several reasons for this reduction, notably the fact that significantly less material is presented in the interactive classes. There are also many examples of excellent concept questions now available. The design of good questions still takes time, but the pre-reading responses make it much easier to design or improve questions. Finally, the need to cover all the content in lectures is removed, so it is mostly no longer necessary to revise material for every lecture based on what was unfinished in previous sessions.

There is a need to dedicate time to process the pre-reading responses immediately before each lecture. The software we developed makes it possible to do this very rapidly. Responses from a class of 200 are now routinely marked and analyzed in 40 minutes, but this requirement remains an issue, especially for early-morning classes.

The question-driven approach demands a dramatic change in how the lecturer acts in class. A difficult change is that the lecturer must learn to stop talking and give the students sufficient time to think and discuss the material with each other (Crouch & Mazur 2001). This change is not possible unless the amount of material to be covered in class is restricted to the essential learning objectives, but even then, many staff find this change of approach counter-intuitive. We found that even very enthusiastic adopters of the new approach benefitted considerably if they were observed and coached in the approach by more experienced colleagues (Donaldson, Rutledge, & Ashley, 2004; McKenzie, Alexander, Harper, & Anderson, 2005; Southwell, Gannaway, Orrell, Chalmers, & Abraham, 2010).

Observations of lectures suggest that more experienced practitioners of active learning teaching are better able to engage the students. Less experienced practitioners are still working to capture the essence of the active learning process and thereby fall somewhere in the middle, no longer providing the full (but limited) benefits of traditional lectures but not yet able to achieve what best practice in the active learning process delivers. The transfer of teaching practices to other team members remains a challenge and further mentoring is required.

DISCUSSION

Why an integrated approach?

The use of multiple instructional practices and tools has been identified as beneficial in previous teaching and learning studies. While the use of particular individual tools and practices has proven valuable (Smith et al., 2009), it is the integration of these practices that is viewed to be the most pedagogically valuable, (Crouch & Mazur, 2001; Deslauriers, et al., 2011; Meltzer & Manivannan, 2002). This integration has been confirmed in our study.

We cannot identify a single aspect of our approach that works above all others; it is the integration of all the practices into a coherent process that makes it such a powerful teaching and learning intervention. Most students are engaged from the first moment by a process that utilizes their previously acquired knowledge and knowledge application (the pre-reading and quiz stage), the challenge of problem solving (clicker questions), the peer instruction (sharing ideas with fellow students) and the general interactions between student and lecturer.

It became clear that the students saw the pre-reading component as an integral part of the complete learning process, including the class sessions. Students involved in this study uniformly agreed that they felt more actively engaged in their learning than in other lectures. The entire process of pre-reading, online quiz, lecturers utilizing feedback to inform the lecture, the clicker questions and the opportunity to interact with both the lecturer and their fellow students offered a complete package for the participants of the focus groups.

One of the hardest aspects of this form of teaching is the design of effective conceptual questions (e.g. Beatty et al., 2006a). Good questions include some ambiguity to encourage deeper thinking or successfully reveal common misconceptions. Academic staff find the latter particularly hard to deal with as they tend to have forgotten the misconceptions they may have once had themselves (Meyer & Land, 2003), although many good question resources are now available. In our approach, the written reading quiz answers provide lecturers with a rich source of relevant material to design (or simply improve) questions that directly address the real misconceptions faced by the students.

Peer discussion as an active learning tool also appears to allow less knowledgeable students to arrive at understanding even when grouped with students of similar abilities, which Smith et al. (2009) suggest provides a constructionist explanation of the development of conceptual understanding in these students.

The activities that the students perform are part of a whole process that provides consistent feedback to both the lecturer and the students at various points in the proceedings facilitating student-material, student-student, and student-lecturer engagement (Kuh, 2008). The key issue identified by Kay and LeSage (2009) was the challenge of quickly responding as new misconceptions arise in class. Our pre-reading analysis means that the lecturer can start every lecture knowing the main problems that students have with the material. Even when the lecture preparation is "just in time", this advance warning makes it much easier to respond in class. The lecture preparation is also much more rewarding as the lecturer knows time in class is spent working on issues relevant to the student cohort.

Difficulties with our approach

Our study has also revealed several problems that arose with our approach. These mostly relate to the implementation rather than the broader principles of active learning, but they must be addressed if the approach is to succeed.

One of the most surprising results from the focus group discussions was that the pre-reading was harder than the teaching staff realised for many students. This is not just that some students are slower readers than others, but the levels of understanding reached were lower than expected. Even after completing the reading and associated quiz and getting a short review in class, only about half the students could give the correct answer to the corresponding concept question. We may need to review the way we approach the pre-reading stage if future analysis confirms that it is a relatively inefficient step in the learning process.

The in-class "peer learning" discussions, on the other hand, are demonstrated to be very effective. However we observe that a small number of students sit alone and do not engage despite regular encouragement (we ask them to talk to other students and also approach them ourselves during the discussion times). We need to find out why these students are avoiding the discussions and provide them with appropriate skills and/or incentives.

The observation of the different staff in class revealed significant variations among the teaching staff in terms of how much they adopted the new approach and how effectively they engaged their students in the process. This is important, as it seems that the full benefits of the active approach do not occur until the teaching is fully changed to the new mode. This makes it extremely important to train and mentor staff who are new to the approach.

Finally, there is a significant degree of technical skill required for our approach. The lecturers must master the use of the analysis software before lectures and the clicker response system during lectures, in addition to delivering the quizzes on the local learning management system. Our teaching team was relatively comfortable with the technical issues, but this might prove more difficult for some teaching staff.

CONCLUSION

This paper presents an approach to question-driven instruction that integrates the in-class discussions with a pre-reading framework providing rich feedback to both the lecturers and students. Some of the key innovations used are software to rapidly identify common problems in the student responses, as well as the mentoring of lecturers new to the approach to improve the discussions.

In conclusion, the data gathered confirms that the active learning teaching framework is a valuable one and that, when the integrated instructional practices are fully adopted, the active learning process has the potential to transform the atmosphere in a full lecture theatre to one that resembles a small tutorial with all its inherent intimacy, with the promise of student engagement and improved learning outcomes. In the words of one of our students:

> *I've realised something . . . that it is all right to get good grades, however, if you understand how you get the good grades and what is going on, you*

> *are actually learning something. . . . In other lectures there isn't that instant feedback. In the clicker questions it is the best when all the answers pile up in the wrong place and then the lecturer understands that most people do not understand the concept. The lecturer understands where people's misconceptions lie and so goes into more depth on that.*

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NOTES

1. Our software package is named "Semant". The source code is available at http://www.smp.uq.edu.au (search for "Semant") although we are not able to provide support for its use.

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