Optimising Student Response Systems for Feedback and Higher-order Thinking in Mathematics

Con Lozanovski, Patrick Tobin

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C. Lozanovski and P. Tobin
Faculty of Arts & Sciences, Australian Catholic University, Australia
Con.Lozanovski@acu.edu.au, Patrick.Tobin@acu.edu.au

Active teaching and learning technologies such as Student Response Systems have seen wide application in higher education over recent decades. This technology boasts a list of potential advantages such as enhancing the student experience and engagement in challenging subjects like mathematics. One of these advantages is immediate feedback for both the students and teaching staff. For students, this feedback is displayed during the lecture in the form of bar-charts allowing individuals to gauge their understanding of materials relative to the entire class in total anonymity. On the other hand, teaching staff can gauge the progress of the class at key intervals of the lecture with the ability to address misconceptions through discussion. Usually, this is the extent to which feedback is used with no recording stored for later analysis. However, there may be instances that necessitate more than brief discussion within a lecture period. It is crucial to both recognise these occurrences and have in place a procedure to subsequently deal with the misconceptions. We propose such a procedure, based on student response times and statistical outcomes, which dynamically composes and focuses subsequent tutorial classes. An in-class example is given that illustrates the approach.

Keywords: Student Response Systems; Clickers; Feedback; Higher-order Thinking; Mathematics Education; Tutorials; Lectures

Introduction

The use of Student Response Systems (SRS)[1] has gained widespread acceptance across broad disciplines at tertiary level. In mathematics, teaching staff view this technology as an opportunity to instil the practice of active teaching and learning – much needed in modern day mathematics lectures (D'Inverno et al, 2003). This practice encompasses feedback, for staff and students, which is an essential aspect of mathematics pedagogy. The overall approval by students and their positive perception of the technology in supporting meta-learning has fuelled the technology's development (see, for example, Kay and LeSage (2009) and Caldwell (2007)). This has been reinforced by the recent surveys carried out on pre-service primary mathematics by Haeusler and Lozanovski, (2010) and Lozanovski et al (2011). The majority of these students revealed that the technology, implemented in a particular way, is helpful and engaging. The technology is well suited and compliments pedagogy in the mathematical sciences (Retkute, 2009). Their use can be adapted to most classroom situations, from large lectures to small groups within tutorials. In fact by c. 2006 it was estimated that some use of SRS existed in almost every university in the USA (Titman and Lancaster, 2011).

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[1] Also known as Audience Response Systems or Personal Response Systems.

A broader use of SRS is found in the application of team-based learning (Haeusler and Lozanovski, 2010) within tutorials. In this application the students form small teams which remain unchanged throughout a course. They respond to questions as individuals and as a team with the opportunity to reflect on the results and review their opinions. Feedback, in the form of bar-charts and discussions with teaching staff, plays an important role in this process. Team-based approaches by definition relinquish one of the key advantages of SRS, that of anonymity (Stowell et al, 2010). However, this is done within a small team which serves to inform through group discussion among team mates as opposed to the entire class.

In a lecture scenario, one hour in duration, students respond directly to short (multiple-choice and/or true-false) questions posed to determine conceptual understanding. These allow the teaching staff to gauge the effectiveness of learning transfer in a class. Typically, the responses for a given question are automatically and immediately displayed in the form of a bar-chart. This (instant) feedback plays two important roles; the first is to inform individual students on their performance relative to the class. This is achieved with total anonymity which is another key advantage of using the technology. On the other hand, teaching staff are presented with an immediate snap-shot of the class' conceptual understanding of the lecture material covered. Ideally, this would be followed by brief discussion addressing any misconceptions. However, feedback obtained in this manner can provide even more valuable information. We propose that SRS feedback should not only be used during a lecture (instant feedback) but analysed post-lecture (deferred feedback) by teaching staff. Indicative results of this analysis would be communicated to the tutorial teaching staff and acted on.

In this paper we investigate the role that feedback plays when SRS are used within a mathematics education courses (although this can be easily generalised to any other discipline). The types of feedback that the technology is capable of are examined along with the distinction between feedback to students and feedback for teaching staff. A classification of feedback for teaching staff is proposed based on student response times and the percentage of correct responses per question. Finally, an illustrative example is given based on a previous study by Lozanovski et al (2011).

Student Response Systems and Feedback

Traditional delivery methods in mathematics education are often seen as too disengaging and ineffective in modern day mathematics lectures (Larsen, 2006). Compounding the issue is the fact that undergraduate mathematics classes are often taken as compulsory service subjects that are not central to the students' interests. The current trend within the Australian education sector of mass education can channel students into subjects they may not have expected. The reality is that mathematics is an essential discipline, underpinning many other disciplines, which a majority of first year undergraduate students will have to face. This can lead them to (further) developing a negative perception that mathematics is too hard and irrelevant (Brown, 2009). Technology, such as SRS, has the potential to change this perception to a positive one (Haeusler and Lozanovski, 2010). Moreover, SRS have the advantage of the ability to provide instant feedback that is directly associated with the class material (Mory, 2004). This permits students to compare their response, the classes' response in totality and with the correct result displayed by the teaching staff.

There are a number of key benefits in using SRS (see, for example, Lozanovski et al, 2011 and de Jong et al, 2009). The technology certainly shows great promise for engaging students in both lecture and tutorial scenarios. Increased student participation not only promotes learning but also elevates their perception of the subject and it certainly has the potential to totally reverse negative perceptions. Improving engagement in class is believed to link directly to good pedagogy (Titman and Lancaster, 2011). However, this expected link is questioned by Dangel and Wang (2008) who focus on the quality of engagement being a determinant on good learning. SRS also have the ability to address one common criticism observed in classes over time and that is the issue of poor feedback. Feedback can be defined as a function that relates to the course material presented which allows comparison between an actual outcome and a desired outcome (Poulos and Mahony, 2008). Providing feedback to students has been recognized as an essential strategy in education (Ramsden, 1998) and SRS provide yet another means to implement this requirement.

Feedback to students should be both appropriate and timely according to Mory (2004) as dictated by the learning and teaching situation (Poulos and Mahony, 2008). The feedback from SRS is certainly ‘timely’ as the system automatically compiles student responses and the results are displayed in the form of bar-charts at the discretion of the lecturer/tutor. However, it must also be deemed ‘appropriate’. Poulos and Mahony (2008) list some appropriate forms of feedback; sufficient, gender-specific, face-to-face and instructor delivered. Weaver (2012) identifies four main themes of feedback that should be avoided: vague comments, no guidance, focus on the negative or unrelated to assessment criteria. The displayed SRS results shown to the class can initiate discussions affording the opportunity to correct widely held misconceptions if this is needed. Given the anonymity in which the data is collated the technology is multi-faceted in its appropriateness. If students were required to raise hands or comment on issues directly it may not allow effective and efficient data collection. This could result in poor response rates or responses affected by student perception of their peers’ opinions (conformity). As a consequence this would then corrupt the feedback process. This issue was raised by Stowell et al (2010) who compared traditional approaches of with SRS. In a lecture scenario, although the feedback is given to the entire class each student can individualise this for their own response. On the other hand, in tutorials students are able to use feedback to help form opinions to be shared with team members. This makes a compelling argument for the technology.

The technology can also provide important feedback for teaching staff on the conceptual understanding of the entire class (lecture scenario) and progress of individual students (tutorial scenario). For teaching staff this feedback is composed of instant feedback and deferred feedback. Instant feedback, for example in the lecture scenario, gives teaching staff a snap-shot of the conceptual understanding of the entire class. This naturally leads to some discussion in order to clarify any misconceptions. However, situations may arise that require more time and attention on particular issues or teaching staff may not immediately identify misunderstanding of a fundamental mathematical concept. To this end, we propose a method whereby Kaplan-Meier estimates, from classical survival data analysis, are used to determine the confidence which students have in responding and the severity of the misconception(s) involved. Once recognised from the lecture scenario the lecturer would transmit this information to tutors and other teaching staff members as a means of focusing on the problem. Tutorials would be a more appropriate arena for dealing with such issues as time constraints are not as essential as in lectures.

Methodology and Practicalities

In the mathematics education courses studied (Lozanovski et al, 2011), students had a traditional lecture and a two hour tutorial. When students entered the lecture or tutorial room they were instructed to pick up their 'Clicker'[2] for use in class. In each lecture and tutorial students would be asked a series of multiple-choice and/or true-false questions. Three SRS questions were posed in the lecture which occupied a total of approximately 16% of the 50 minute class. After displaying the SRS question on PowerPoint, the lecturer would then read the question to the class and highlight the possible answers. Students would then attempt to answer the question by depressing a corresponding number on their key-pad ('Clicker'). The lecturer then closes the SRS question and by a simple click of the mouse button displays the collective results to the class. The generated bar-chart presented is then discussed giving both lecturer and students an opportunity to raise any outstanding issues and address misconceptions.

The lecture scenario encounters important issues when implementing SRS, e.g. time constraints (see Lozanovski et al, 2011), whereas some of these are not as much an issue in tutorials. In tutorials, the technology was easily incorporated with ample time for reflection and discussion. The (standard) ten tutorial questions were distributed to students at the beginning of the tutorial. For each tutorial question a corresponding multiple-choice question was developed within PowerPoint. Primarily, the multiple-choice questions were used to gauge understanding and provoke discussion, both within groups and the whole class. After the class attempted a question the associated multiple-choice question was presented. Student's as individuals responded by depressing a corresponding number on their 'Clicker'. The result, a bar-chart, was then presented to the entire class and students were instructed to form discussions within their groups. The multiple-choice question[3] was then reset and each group was instructed to submit their results. This was done collectively. Finally, the group results were displayed, again using another bar-chart and a class discussion followed. It should be noted that the majority of students had no issues using the technology at the first tutorial after having encountered them during the first lecture of the course.

The SRS data was saved from PowerPoint and the third-party proprietary software onto hard-disk from both lectures and tutorials. The data saved from lectures was analysed using SPSS. If required (see classification below) lecturer's instructed tutors and other teaching staff to focus on certain mathematical misconceptions.

Classification and Analysis of Feedback

The student response times were studied by Lozanovski et al (2011) in order to address the issue of implementing the SRS in mathematics lectures effectively. The probability that a student will take longer than a specified time to respond produces an empirical distribution. Maximum likelihood estimators for this yield the Kaplan-Meier estimates from classical survival data analysis (see, for example, Titman and Lancaster, 2011). This generates confidence intervals on 'response' times' – the time to final response or

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[2] A 'Clicker' is a handheld device (keypad) resembling a garage-door opener that is used by students to transmit their response.

[3] This was the same multiple-choice question as the first one which was marked with a (red) capital R to denote this fact.

allows censored data to be used where the response was timed out. A classification based on final response times[4] (FRT) and overall results is proposed as the following.

- **C1**. Minimal lecture discussion: FRT <30s and Correct Responses High%
- **C2**. Lecture discussion needed: FRT <30s and Correct Responses Medium%
- **C3**. Reinforced in tutorial discussion: FRT <30s and Correct Responses Low%
- **C4**. Lecture discussion needed: FRT (30s, 100s) and Correct Responses High%
- **C5**. Tutorial discussion: FRT (30s, 100s) and Correct Responses Low% to Medium%
- **C6**. Tutorial focus: FRT >100s (timed out) and Correct Responses Low% to High%

Note that the FRT can be taken from two standard deviations of the response times of the entire class. This would prevent outliers from corrupting the classification. High%, Medium% and Low% could be calculated as moving averages throughout the semester from initial values.

In the first case of the classification if the class responds within 30 seconds and a high percentage are correct only minimal discussion is required. It should be affirmed that the few students who are still struggling with the material seek one-on-one support with either teaching staff or whatever support programs are in place. On the other hand, if more students submit an incorrect response within the same time then this suggests these students are confident with their response despite being incorrect. A clear discussion is therefore needed to iron out this misconception. The lecturer may use the bar-chart as a starting point and work through each incorrect response. Finally, for responses within 30 seconds, if the majority of the class fails to respond correctly then further discussion on the course materials may be required in tutorials.

The issue of promoting higher-order thinking over surface learning when teaching with SRS using multiple-choice questions has been raised by Dangel and Wang (2008). These questions should require higher-order thinking over extended computational time. That is, students should not have to labour over involved computational tasks that merely require low-order thinking. Therefore, if SRS response times are between 30 seconds and 100 seconds this should be looked at closely by teaching staff. In the first case, if a high percentage of students respond correctly this could suggest a lack of confidence. A lecture discussion should then focus on elevating self-efficacy and ability. However, if correct responses only make up medium to low percentages then this suggests a deeper learning problem and the specific course materials should be re-visited in tutorials. Finally, if the response times are timed-out, i.e. by definition this is when the FRT is greater than 100 seconds, then this suggest a serious misunderstanding of the course material requiring urgent attention.

As an illustrative example, consider the results presented by Lozanovski et al (2011) which lead to the step graph as shown in figure 1.

[4] Taken after the SRS question is made active – open to receiving ‘Clicker’ responses.

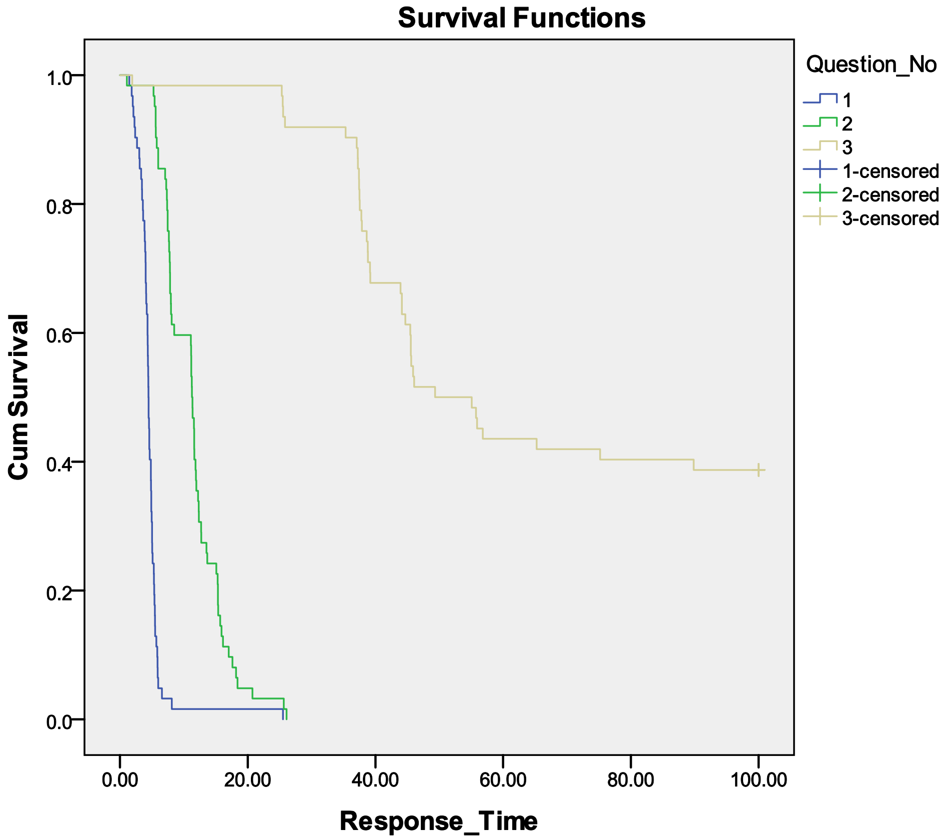

Figure 1. Graph of Cumulative Response Times

The first question is classified C1 since 95% of students responding within 10 seconds and the FRT was less than 30 seconds. This was reinforced with high percentage (90%) of correct responses. It is interesting to note that some students took considerably longer to respond relative to their peers. Several reasons have been suggested to explain this common phenomenon (D'Inverno et al, 2003). However, for our purposes these outliers could be screened out to achieve more reliable results.

The second question is C2 since 95% of students responded within 20 seconds, the FRT was again less than 30 seconds, but only a medium percentage (50%) submitted a correct response. This question required more classroom discussion and this started by addressing all the incorrect responses.

In the last question 39% of students could not respond within 100 seconds (timed-out) and of the 61% that did reply within 100 seconds only a low percentage (37%) responded correctly. This question is of type C6. It is evident that this highlights a serious problem that requires substantially more teaching time. Although a classroom discussion was then initiated, sufficient time could not be afforded in the lecture. It was then deemed necessary to focus on the misunderstanding of the course material in tutorials. This feedback is useful to the lecturer as it shows that more time on the idea is needed for learning to occur.

SRS Higher-order Thinking Questions

Consider the following SRS question that would typically be in the form of a multiple-choice question:

SRS Question: The value of *x* that satisfies the linear equation $4x+3=-9$ is

A. 1
B. -9
C. -3
D. 9
E. -4/3

We can easily complicate this question simply by introducing more repetition and therefore extending the computational time. For example, consider the following alternative to the SRS question posed above:

SRS Question: The value of *x* that satisfies the linear equation $3x+4+5x+6-4x+3=1$ is

A. 1
B. -9
C. -3
D. 9
E. -4/3

Although the question seems, at first, to be more difficult, it does not invoke higher-order thinking to arrive at the solution. The equation is actually identical to the one in the previous SRS question, however, made to appear more complicated than standard form. This example is based on the conclusions drawn by Lozanovski et al (2011) who analysed the student response times with questions that required extended calculation time (ECT), which are viewed as time consuming but not necessarily insightful in pedagogical terms.

The following SRS question is also on linear equations however it possesses a significant jump in the collective cognitive processes required to solve it. Furthermore, there is also a need for synthesising the desired constituents of the equation and to justify steps towards its evaluation.

SRS Question: The equation $\frac{3(x+1)-15}{2}=-7x+2$ is equivalent to

A. $3(x+1) = -14x-15$
B. $3(x+1) = -14x+4$
C. $3(2x+1) = -7x+2$
D. $3(2x+1) = -14x+1$
E. $3(x+2) = (-7x+2)/2$
G. $3(2x+1) = (-7x+2)/2$
H. $3(x+2) = (-7x+2)/15$

This SRS question focuses on Evaluation and Analysis where neither a correct numerical solution is desired nor identification to standard form. The problem requires a higher level of thinking as students will also be dealing with fractional coefficients.

Discussion

In this paper we aimed to bring together several strands of action research on the use of SRS in mathematics classes. Together with observations on their capabilities and limitations we focused on the role of feedback with the use of questions that required higher-order thinking. The importance of effective feedback is repeatedly stressed by educators and SRS give opportunities for students to receive this in real-time. Students gain rapid awareness of what they know or don't know at the same time as seeing how they stand with their peers and all in a nonthreatening format. Lecturers receive feedback on a class-wide basis which is useful for assessing student progress in a course. In this investigation we proposed that SRS feedback could not only be used during a lecture (instant feedback) but analysed post-lecture (deferred feedback) by teaching staff. Indicative results of this analysis would be communicated to the tutorial teaching staff and acted on accordingly.

Time constraints on the use of SRS technology are a serious issue in lectures and the need to use the 'Clickers' to test student understanding at deeper levels reinforces this. The judicious choice of lecture SRS questions needs a fine balance in promoting confidence without testing the trivial or computationally tedious. Concepts should be paramount in these types of questions. 'Clicker' use is as easy and rapid for any level of question, but it has been observed on many occasions that students do take time to answer what they hope is correctly.

There are well known advantages and drawbacks associated with multiple-choice questions, (for a comparison with constructed responses see, for example, Kobrin et al, 2011), nevertheless they are well suited in a lecture scenario. Given recent advances in technology/software it is now possible to accommodate 'worded' constructed (limited symbolic) responses within SRS[5]. However, in mathematics, this would be of limited benefit over multiple choice questions alone.

Effective use in lectures will require care in selecting many questions with higher cognitive level content which are still only conceptual in execution. Effective response to results requires a plan that allows the lecturer to decide promptly what action is needed further depending on the SRS feedback. Effective use in this context sees the 'Clickers' used in group work in tutorials which sacrifices some anonymity in exchange for overcoming learning deficits.

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[5] See, for example, the online resource by ©Polleverywhere @ http://www.polleverywhere.com/

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