ENGAGING STUDENTS IN LARGE LECTURES OF INTRODUCTORY BIOLOGY AND MOLECULAR BIOLOGY SERVICE COURSES USING STUDENT RESPONSE SYSTEMS

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ABSTRACT
Student response systems are an efficient, inclusive and engaging strategy to increase student participation in large-enrolment classes. Combined with effectively designed questions, they can stimulate and probe deeper conceptual understanding and enhance pedagogical outcomes. Hardware 'clickers' have been used and reported extensively but are limited in the variety of possible responses that can be gathered; new web-based student response systems that leverage the increasingly ubiquitous mobile devices that students bring to lectures offer a flexible and stimulating way for students to be emotionally and intellectually invested in knowledge building and conceptual understanding. We describe our experiences with hardware and web-based student response systems, highlighting both well-reported and novel applications of these systems to transform lectures from passive information delivery environments to active learning spaces for both students as well as lecturers.

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INTRODUCTION
The concept of lectures as large-scale instructional tools has remained largely unchanged for many hundreds of years (Sheely, 2006). The lecture model is usually perceived by students to be didactic and impersonal, involving one-way transmission of information from the lecturer to students, who sit and passively take notes (White, 2006). However, the effectiveness of this mode for information dissemination and explanation over the course of a typical 50-minute undergraduate lecture has been questioned, since students typically have short 15-20 minute attention spans (Stuart & Rutherford, 1978; Frederick, 1986). More recently the current generation of learners, sometimes labelled the 'Millennials', or the 'Net Generation', or 'Digital Natives' (McNeill, 2011), has been found to have even shorter attention spans of seven minutes (Baker, Matulich, & Papp, 2007) or less (Bunce, Flens, & Neiles, 2010). The problems associated with this misalignment of teacher and student expectations are further compounded by the prevalence of very large classes, e.g. n=550, in many introductory undergraduate subjects. Working in large spaces distances the lecturer and the student, depersonalising the learning experience and resulting in student disengagement (White, 2006; Walker, Cotner, Baepler, & Decker, 2008). The prognosis for successful learning and engagement in 'traditional' lectures therefore appears bleak (Powell, 2003).

Nevertheless, it seems that students perceive lectures as an intrinsic component of their learning journey at university, and consider the discipline and the interaction with their peers and their lecturers of high importance in this process (Gysbers, Johnston, Hancock, & Denyer, 2011). The challenge for lecturers, therefore, is to re-engage students in lectures so that the time they are willing to spend in that environment is more pedagogically fruitful. This requires lecturers to adopt innovative teaching methodologies for lectures that are more student-centred and promote active learning (Allen & Tanner, 2005; Walker et al., 2008; Armbruster, Paterl, Johnson, & Weiss, 2009). A number of reports have highlighted effective instructional design principles for lectures such as problem-based group discussions (Kumar, 2003; Walker et al., 2008; Armbruster et al., 2009), pre-prepared questions on worksheets or in workbooks (Meltzer & Manivannan, 2002; Bridgeman, 2012), and various systems that allow the lecturer to quickly collect and evaluate student responses to questions posed (e.g. Meltzer & Manivannan, 2002; Sharma, Khachan, Chan, & O'Byrne, 2005; Blood & Neel, 2008). Some common themes linking these initiatives include the reorganisation of lecture time into digestible blocks interspersed with learner-centred activities, an emphasis on student discussions, and the integration of formative assessment.

These three themes can be addressed through the effective implementation of student response systems in lectures. Known by many names (e.g. classroom response system, audience response system, personal response system, classroom network, and the catchy 'clickers'), student response systems are fundamentally electronic tools that allow an instructor to poll their students in real-time (extensively and thoroughly reviewed in Caldwell, 2007; Lantz, 2010; Keough, 2012; Vicens, 2013). These modern student response systems build upon the 'hands-up' or 'hold-up-a-card' approaches which have been traditionally used to engage students in lectures (e.g. Meltzer & Manivannan, 2002; Bates, Howie, & Murphy, 2006), and are much more effective in gauging overall student understanding, with few of the age-old problems associated with interrogating an unresponsive audience (Schell, Lukoff, & Mazur, 2013). Early student response systems reported in the literature were based on specialised commercial hardware where physical devices in students' hands were linked via a radiofrequency or infrared connection to a receiver, which then interfaced with software to present poll results (e.g. Burnstein & Lederman, 2001; Sharma et al., 2005; Bates et al., 2006; Hoffman & Goodwin, 2006; Ribbens, 2007; Moss & Crowley, 2011). However, these systems were often hampered by technical issues (Barnett, 2006; Hoffman & Goodwin, 2006; Caldwell, 2007; Keough, 2012) and did not provide much interaction flexibility beyond simple single-question multiple-choice polls (Schell et al., 2013). Nevertheless, lecturers who implement student response systems highlight gains in student engagement (Knight & Wood, 2005; Barnett, 2006; Hoffman & Goodwin, 2006; Blood & Neel, 2008; Crossgrove & Curran, 2008; Addison, Wright, & Milner, 2009; Keough, 2012), examination performance (Sharma et al., 2005; Blood & Neel, 2008; Crossgrove & Curran, 2008; Addison et al., 2009; Keough, 2012) and even attendance (Burnstein & Lederman, 2001; Bullock, LaBella, Clingan, Ding, Stewart, & Thibado, 2002; Ribbens, 2007) in lectures. However as with all educational technology, student response systems should support pedagogy and not the reverse (Watson, 2001; Gray & Steer, 2012), and should not be viewed as a panacea for poor student engagement (Beatty, Gerace, Leonard, & Dufresne, 2006). In recent years, web-based applications have been developed that leverage the increasingly ubiquitous mobile devices such as laptops, smartphones and tablets and allow a more diverse range of interactions including short-answer and even drawing-based responses (University of Queensland, 2011; Robb & Shellenbarger, 2012; Bhargava, Lackey, Dhand, Moshiri, Jambhekar, & Pandey, 2013; Schell et al., 2013; Vicens, 2013). Benefits of integrating these modern student response systems into lectures involve harnessing the Millennials' need for immediacy as well as their obsession with technology (Wilson, 2004; McNeill, 2011) to leverage strong pedagogical outcomes.

Here, we report our experiences with both traditional hardware-based clickers as well as more modern web-based student response systems in large introductory biology as well as molecular biology and genetics lectures with up to 500 students. After our initial experiences with a hardware-based system in 2009, we decided to take advantage of the portable mobile devices that Millennials were increasingly bringing to class (McNeill, 2011) by moving to a free and intuitive web-based system, *Socrative* (www.socrative.com). By integrating the students' favourite devices with their learning, the stage was set for increased engagement (Kolb, 2011). Through our use of these systems, we aimed to enhance students' pedagogical as well as emotional engagement (Walker et al., 2008) with course material. This report builds upon the recent emergence in the higher education literature of *Socrative* (Binder, 2013; Méndez-Coca & Slisko, 2013) as well as other web-based student response systems (e.g. Schell et al., 2013; Vicens, 2013).

IMPLEMENTATION

Hardware-based clickers were originally integrated into first year biology classes in 2009 and used in the early lectures to quickly determine the level of prior knowledge for key concepts across the cohort (Taylor, 2008; Ashwin & Trigwell, 2012). This approach had a primarily teacher-centred motivation in helping us to gauge the extent of variation in knowledge and understanding, and thus the extent to which our curriculum expectations may be realistic and achievable (McCune & Hounsell, 2005). On a practical level the exercise involved considerable outlay of time and organisation both within and outside the lectures, since clickers (handset hardware) had to be distributed to, and collected from, 500 students at the beginning and conclusion of each lecture, then transported to new venues for repeat and subsequent lectures. With these hardware-based clickers, we also experienced a number of technical issues, such as the USB receiver dongle not being recognised by the presenting computer due to missing driver files. Clearly these issues can provide a strong disincentive for lecturers to incorporate such interactions into their lectures but, notwithstanding this challenge, our experiences provided useful insights for both lecturers and students. The multiple choice question format has obvious disadvantages in determining the extent of variations in misunderstanding since responses are limited to the available answers. To alleviate this problem clicker questions were paired with open-ended written responses, where students had to create individual answers for separate analysis by the lecturer. Formative feedback which addressed the range of misconceptions was then incorporated into subsequent lectures and laboratory classes to complete the feedback loop and maintain continuity (Fisher, Cavanagh, & Bowles, 2011). The multiple choice responses were automatically tallied by the system, and displayed immediately for everyone to see. Students could remain safe and anonymous while seeing that there were other people in the class who were similarly confused about the concept (Wilson, 2004; Knight & Wood, 2005; Ribbens, 2007). Other students took the opportunity to explain the reasons for their answers to the class, thereby opening up discussion about the various choices, and allowing their peers to re-evaluate their answers. The immediacy of the system therefore provided instant validation and feedback, which is an important consideration when teaching Millennials (Blood & Gulchak, 2013). From the teaching perspective these impromptu discussions required a change of direction in the lecture to address the arguments, but created a valuable ‘teaching moment’ when everyone was engaged with the topic (Knight & Wood, 2005; Trigwell, Prosser, Martin, & Ramsden, 2005), thus reflecting an in-lecture form of Just in-Time Teaching (Marrs & Novak, 2004). Student reaction to the outcomes provided interesting insights whereby, for some, identifying with a group provides comfort while others are stimulated to review their thinking (Ribbens, 2007). In addition, the interactivity and student discussion provided a challenge to those expecting to sit back and listen, and set a precedent for future activity and involvement in lectures.

Web-based student response systems delivered many advantages including more flexible question types as well as ease of use. Additionally, from 2011, gradual improvements in WiFi signal in lecture theatres allowed students to access the internet on their own devices. This provided us the opportunity to explore web-based student response systems. We selected *Socrative* because it was free, easy to set up, offered a range of question options, and had a modern, intuitive interface. Student access was simple – all they needed to do was to navigate to a URL using the browser on their mobile device and enter a designated room number. A common challenge in these bring-your-own-device scenarios is the lack of cross-platform apps (Eisele-Dyrli, 2011; Nykvist, 2012), but the *Socrative* system obviates this concern by being entirely web-based and able to run in any modern browser. Additionally, the responses are anonymous, providing a safe non-judgmental environment which is significantly more conducive to student participation (Wilson, 2004; Wood, 2004; Knight & Wood, 2005; Bates et al., 2006; Ribbens, 2007; Lantz, 2010; University of Queensland, 2011; Blood & Gulchak, 2013).

The *Socrative* student response system was integrated into lectures at a number of points (Figure 1). In the few minutes before the formal start of the lecture, a fun icebreaker question was displayed along with a quick response (QR) code which, when scanned using a smartphone, would take students directly to the appropriate URL for logging into the system (Figure 2). The use of QR codes in education is increasing, and using the QR code here was a simple way to enhance perceived technological novelty (Chaisatien & Akahori, 2006). The function of the icebreaker question was two-fold: (1) it allowed students time to log into the system before the start of the lecture and, more importantly (2) it humanised the large crowd (Bates et al., 2006). So often in large lectures do students feel unnecessarily lost and disconnected (White, 2006, 2007), and just by seeing that their responses are shared by others in the class (Knight & Wood, 2005) puts students at ease.
The lecture content was subsequently divided in portions suitable for the Millennial students’ attention span (Baker et al., 2007; Bunce et al., 2010), interspersed with questions (e.g. Figure 3) that allowed us to confirm the extent of student understanding and recapture their attention (Lantz, 2010; Vicens, 2013). To do this, each question was crafted such that distractors were plausible and targeted different misconceptions, and the question was designed to not be too easy or too difficult. Additionally, an ‘I don’t know’ option was provided so that we could accurately gauge specific misunderstanding without the noise of guessed responses (Caldwell, 2007). Students were encouraged to discuss the question in a small group before responding and these breaks therefore allowed students to recover their attention and undertake deeper learning by actively participating in the lecture (McLaughlin & Mandin, 2001; Kenney, 2012). Also, understanding student misconceptions through such formative assessment tools could reveal weaknesses that lead to reflection and improvements in teaching effectiveness (Beatty et al., 2006; Lantz, 2010). Although we have not tried the poll-discuss-repoll strategy, where peer instruction is applied when a majority of the responses are incorrect, often leading to improvements in correct responses (Knight & Wood, 2005; Crossgrove &

Curran, 2008; Addison et al., 2009), this would be straightforward to implement and would probably lead to even better learning outcomes.

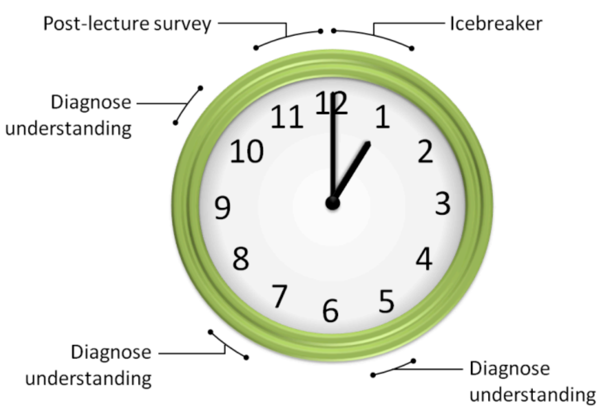

Figure 1: Overview of student response system usage in a typical 60 minute lecture block.

Figure 2: Example of an icebreaker question displayed before the start of a lecture.

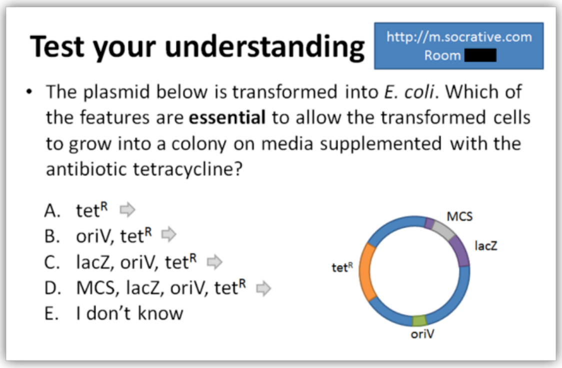

Figure 3: Example of an understanding diagnosis question asked during a lecture.

In addition to single-question multiple-choice responses, we have started to apply the *Socrative* student response system to formatively assess higher-level understanding. For example, students were asked to design a set of oligonucleotide primers to amplify a sequence of DNA, and enter the primer sequences via open-ended short-answer responses. Another question involved students applying knowledge from a previous lecture to an unfamiliar scenario, essentially providing an applied short-answer response similar to the question in Figure 3. These short-answer responses, enabled by the more flexible web-based student response system, require synthesis and hence provide a more effective learning opportunity (Bjork & Bjork, 2011). Indeed, these uses of student response systems, where students need to apply and synthesise knowledge, are still emerging (Dangel & Wang, 2008). One curiosity of the short-answer responses, however, was that some students enjoyed the opportunity for their response to be displayed on the big screen so much that they posted inappropriate comments – this issue can be circumvented by hiding responses until the lecturer has had a chance to filter them.

Another application of a flexible web-based student response system, which is less frequently reported in the literature, is the ability to gather immediate feedback on lecture understanding and lecturer performance from students. Student feedback is a powerful tool for teaching improvement (Harvey, 1999; Fogg, 2007) and should be collected as soon as possible after an instructional event (Richardson, 2005); what better time than immediately after the lecture while the experience is still fresh in students' minds? Therefore, as the students were packing up after each lecture where *Socrative* was used, we started a voluntary four-question post-lecture survey to quickly evaluate the rate of delivery, utility of *Socrative*, general understanding of material, as well as any other issues that students had (Figure 4). Survey results then informed changes in our teaching for subsequent lectures.

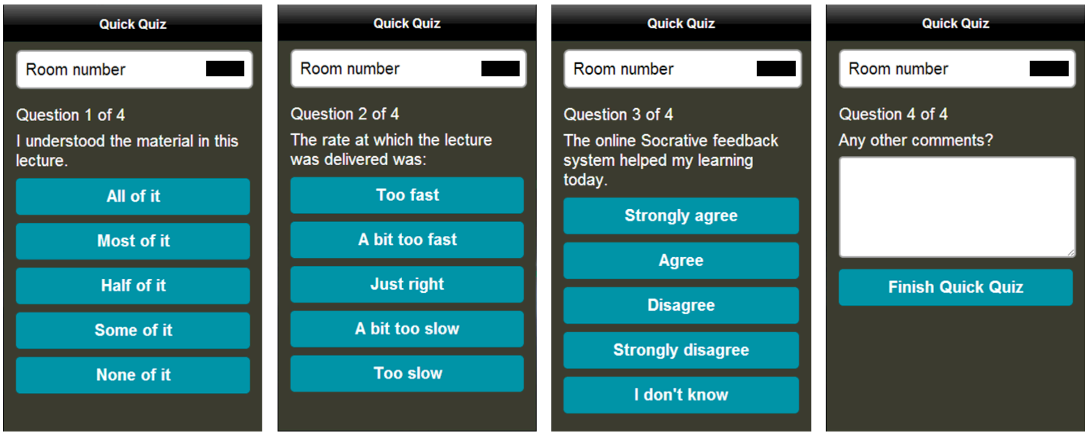

Figure 4: Example of survey delivered immediately after the conclusion of each lecture to receive timely feedback from students about our lecturing.

EFFECTS ON STUDENT ENGAGEMENT

Students were overwhelmingly positive about our application of student response systems, both qualitatively and quantitatively (Figure 5), indicating in post-lecture surveys (e.g. Figure 4), and in wider forums, that the system aided their learning:

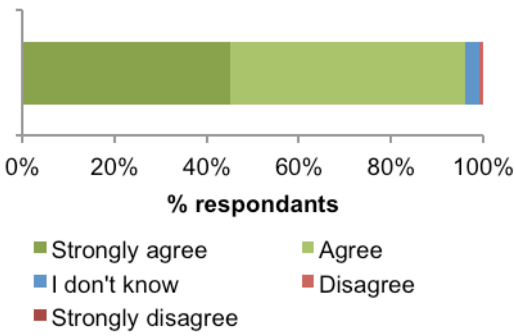

Figure 5: Perceived helpfulness of *Socrative* student response system. Helpfulness was rated on a five-point scale in response to the question, 'The online Socrative feedback system helped my learning today', n=224.

> *I was very impressed with aspects of the lectures like the inclusion of some multi choice questions during the lecture to break up the flow of content delivery and help people to reflect critically on what they know.*

> *Quiz questions made for engaging and interactive learning.*

I especially liked answering questions on socrative during the class. It's not intimidated [sic] if you get anything wrong as no one knows it was you, but if you are right and others are wrong it really fills [sic] good.

I enjoyed using the interactive program. It made the lecture more interesting.

Some of the most prevalent themes in student feedback was that the student response systems enhanced their engagement with the material, that the interactivity made the lecture more interesting, and that breaking up the lecture aided concentration (Knight & Wood, 2005; Bates et al., 2006; Ribbens, 2007; Addison et al., 2009). Additionally, it was particularly pleasing to see students reflecting on their learning experience through the post-lecture survey, suggesting that the student response system, together with in-lecture questions, allowed them to apply and assess their knowledge in a safe environment (Knight & Wood, 2005; Bates et al., 2006).

Perhaps more striking was that the students recognised that we were using these systems not as technological gimmicks but because we genuinely cared about their learning. This appreciation has been suggested to enhance student engagement and learning outcomes (Baker et al., 2007).

The online multiple choice stuff gave us a chance to actually think about it and give answers rather than just sit there waiting for you to give the answers. Also showed you really cared about our level of understanding which was nice :) thankyou!!

In addition, our data showed a correlation between the reported helpfulness of the system and students' perceived level of understanding immediately after a lecture (Figure 6). Predominantly, students who strongly agreed that *Socrative* helped their in-class learning tended to report higher levels of understanding (Figure 6). Interestingly, the students (n=2) who found *Socrative* unhelpful also reported understanding the majority of the lecture material; this might be due to a perception that the questions posed and discussion provided were insufficiently interesting or challenging (Ribbens, 2007). Further information would be required to determine if students thought the system was helpful because it helped them to understand the material better, or if students who were better able to understand the material would naturally consider formative in-lecture assessment helpful.

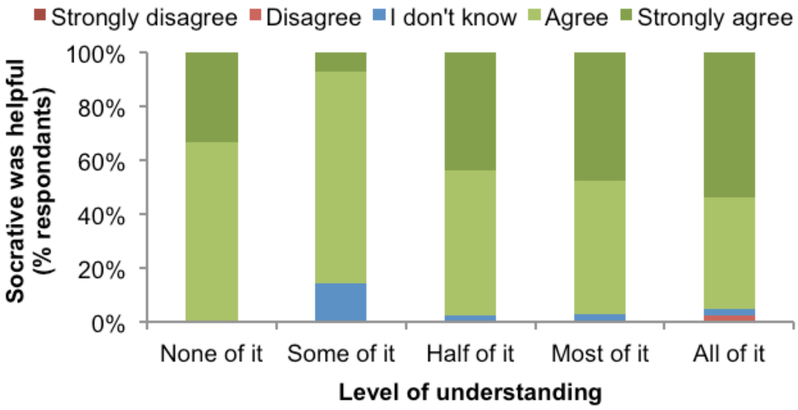

Figure 6: Perceived level of understanding correlated with perceived helpfulness of *Socrative* student response system. Helpfulness was rated on a five-point scale in response to the question, 'The online Socrative feedback system helped my learning today', n=249. The trend was not observed in the 'none of it' understanding category because of the low number of responses in that category (n=3). No students responded 'strongly disagree'.

Interestingly, our post-lecture survey data also showed a correlation between speed of delivery and understanding of material (Figure 7). This relationship has been reported qualitatively (Flowerdew & Miller, 1996) and our immediate data provides further support for this common assumption. In fact, post-lecture data and student comments also played a big part in our development as teachers. For example, student feedback on rate of delivery and other comments allowed us to adapt our teaching to their needs, and subsequent comments are reflective of these adaptations.

Pacing was much nicer today than for the past weeks. THANKS!

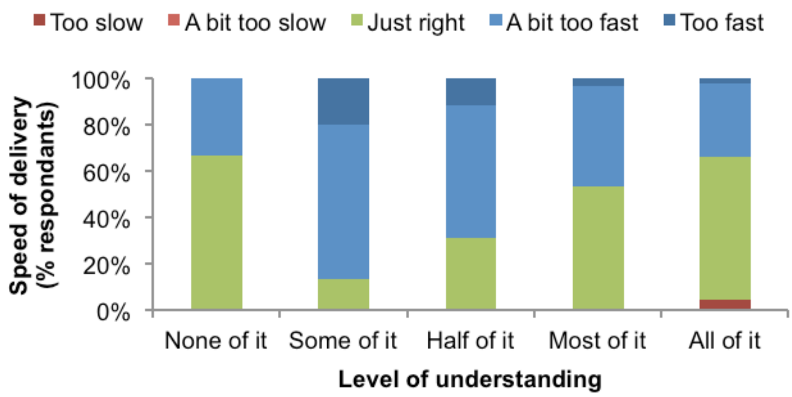

Figure 7: Perceived level of understanding correlated with perceived speed of delivery of lecture material. Speed of delivery was rated on a five-point scale from too slow to too fast, n=224. The trend was not observed in the 'none of it' understanding category because of the low number of responses in that category (n=3).

IMPLICATIONS FOR PRACTICE

The questions that are presented to students for response need to be carefully designed and targeted for maximum effectiveness (Beatty et al., 2006), reiterating the concept that technology is just support for pedagogy (Gray & Steer, 2012). When used as tools to enhance student engagement and deeper understanding, only 3-5 questions taking roughly 10-15 minutes can be comfortably accommodated in a 50 minute lecture, especially since time needs to be allowed for instructive student discussion and review of troublesome concepts (Bates et al., 2006; Addison et al., 2009; Vicens, 2013). All questions used should address specific pedagogical goals beyond just content memorisation; the questions presented to students should allow for application, analysis and even deeper perceptual change (Beatty et al., 2006). This means that the questions used in conjunction with student response systems need to be conceptual and involve applying/reinforcing new knowledge, integrating concepts from previous lectures, and extending current understanding to new contexts (Bates et al., 2006; Addison et al., 2009; Vicens, 2013). Questions can also be used to generate lively discussion and debate amongst students if multiple answers are equally plausible or commonly misconceived (Beatty et al., 2006; Caldwell, 2007). Although it is true that such 'question-driven instruction' does not necessitate a student response system to be effective (Beatty et al., 2006), the enhanced interactivity, anonymity, immediacy and flexibility provide distinct advantages.

An often-feared implication of integrating student response systems and other forms of interactivity in lectures is their non-trivial temporal load and the concomitant reduction in content coverage that necessarily ensues (Knight & Wood, 2005). Suggestions include placing the responsibility of assuming some of this basic knowledge onto students outside of lecture time (Knight & Wood, 2005; Bates et al., 2006), such as through the use of flipped lectures. However, the ability to apply and analyse concepts rather than merely recall factual information is a more important teaching outcome which also benefits information retention (Kitchen, Bell, Reeve, Sudweeks, & Bradshaw, 2003). Since basic content information is now so widely accessible, we posit that a re-engineering of lectures through use of the open-ended response process, which allows us to focus on certain concepts at a deeper level by actively involving students in the learning process, will be much more beneficial in the long term. Another outcome of the effective use of student response systems in large classes is that they essentially transform a one-way lecture into a two-way learning experience (Burnstein & Lederman, 2001; Bates et al., 2006) where the students learn from the lecturer and each other, while the lecturer also learns from the students and constantly adapts to their learning needs. For some instructors this may present an uncomfortable, and unfamiliar, situation since the live lecture needs to incorporate in-built flexibility to accommodate student discussion and revisiting concepts (Bates et al., 2006; Vicens, 2013). In addition, the experience of allowing students to discuss responses may be quite disruptive in a large class and such a novel situation may be confrontational as the control of the time and space shifts from lecturer to students (Bates et al., 2006). Additionally, our application of student response systems extends beyond flexibility within lectures, as student feedback immediately after lectures can inform changes and improvements to teaching approaches in subsequent lectures.

Despite initial resistance to implementing student response systems in lectures, practitioners who take the proverbial plunge, and invest in properly integrating these systems into their classes, quickly discover that the pedagogical benefits for both their students and themselves far outweigh the time needed to redesign lectures and the realignment of content that may need to be moved into private study (Wood, 2004; Bates et al., 2006; Ribbens, 2007).

CONCLUSIONS

Due to the ability of student response systems to enhance student engagement and other pedagogical outcomes (Bates et al., 2006) and perhaps also due to anything technological being viewed as new and exciting (Watson, 2001), student and instructor feedback that we observed and that is reported in the literature (e.g. Wood, 2004; Bates et al., 2006; Caldwell, 2007; Crossgrove & Curran, 2008; Addison et al., 2009) is overwhelmingly positive. To be effective, these systems need to be applied with a flexible mindset and appropriate preparation, such that students are challenged to engage with the material through the technology. Although it is entirely possible that the pedagogical benefits are only perceived because of the technological novelty of these systems (Blood & Neel, 2008), student response systems are nonetheless easily implementable that can turn silent passive lectures, where crickets are chirping, into engaged active lectures where students are clicking.

REFERENCES

Addison, S., Wright, A., & Milner, R. (2009). Using clickers to improve student engagement and performance in an introductory biochemistry class. *Biochemistry and Molecular Biology Education, 37*(2), 84-91.

Allen, D., & Tanner, K. (2005). Infusing active learning into the large-enrollment biology class: seven strategies, from the simple to complex. *Cell Biology Education, 4*(4), 262-268.

Armbruster, P., Patel, M., Johnson, E., & Weiss, M. (2009). Active learning and student-centered pedagogy improve student attitudes and performance in introductory biology. *CBE-Life Sciences Education, 8*(3), 203-213.

Ashwin, P., & Trigwell, K. (2012). Evoked prior experiences in first-year university student learning. *Higher Education Research & Development, 31*(4), 449-463.

Baker, R., Matulich, E., & Papp, R. (2007). Teach me in the way I learn: Education and the internet generation. *Journal of College Teaching & Learning (TLC), 4*(4), 27-32.

Barnett, J. (2006). Implementation of personal response units in very large lecture classes: Student perceptions. *Australasian Journal of Educational Technology, 22*(4), 474-494.

Bates, S. P., Howie, K., & Murphy, A. S. J. (2006). The use of electronic voting systems in large group lectures: challenges and opportunities. *New Directions, 2*, 1-8.

Beatty, I. D., Gerace, W. J., Leonard, W. J., & Dufresne, R. J. (2006). Designing effective questions for classroom response system teaching. *American Journal of Physics, 74*, 31.

Bhargava, P., Lackey, A. E., Dhand, S., Moshiri, M., Jambhekar, K., & Pandey, T. (2013). Radiology Education 2.0—On the Cusp of Change: Part 1. Tablet computers, online curriculums, remote meeting tools and audience response systems. *Academic Radiology, 20*(3), 364-372.

Binder, P. (2013). The intersection of ethical decision-making modules and classroom response systems in business education. Paper presented at the *The Future of Education*, Florence, Italy. Retrieved June 9, 2013, from http://conference.pixel-online.net/foe2013/common/download/Paper_pdf/115-ENT07-FP-Binder-FOE2013.pdf.

Bjork, E. L., & Bjork, R. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. *Worth Publishers, New York, NY*, 56-64. Retrieved June 14, from http://bjorklab.psych.ucla.edu/pubs/EBjork_RBjork_2011.pdf.

Blood, E., & Gulchak, D. (2013). Embedding “Clickers” Into Classroom Instruction: Benefits and Strategies. *Intervention in School and Clinic, 48*(4), 246-253.

Blood, E., & Neel, R. (2008). Using student response systems in lecture-based instruction: does it change student engagement and learning? *Journal of Technology and Teacher Education, 16*(3), 375-383.

Bridgeman, A. J. (2012). *Using very short writing tasks to promote understanding in chemistry.* In M. Sharma & A. Yeung (Eds.), *Proceedings of the Australian Conference on Science and Mathematics Education 2012* (pp. 110-117). Sydney, NSW: UniServe Science.

Bullock, D., LaBella, V., Clingan, T., Ding, Z., Stewart, G., & Thibado, P. (2002). Enhancing the student-instructor interaction frequency. *The Physics Teacher, 40*, 535.

Bunce, D. M., Flens, E. A., & Neiles, K. Y. (2010). How long can students pay attention in class? A study of student attention decline using clickers. *Journal of Chemical Education, 87*(12), 1438-1443.

Burnstein, R. A., & Lederman, L. M. (2001). Using wireless keypads in lecture classes. *The Physics Teacher, 39*, 8-11.

Caldwell, J. E. (2007). Clickers in the large classroom: Current research and best-practice tips. *CBE-Life Sciences Education, 6*(1), 9-20.

Chaisatien, P., & Akahori, K. (2006). *Introducing QR code in classroom management and communication via mobile phone application system.* Paper presented at the World Conference on Educational Multimedia, Hypermedia and Telecommunications.

Crossgrove, K., & Curran, K. L. (2008). Using clickers in nonmajors- and majors-level biology courses: student opinion, learning, and long-term retention of course material. *CBE-Life Sciences Education, 7*(1), 146-154.

Dangel, H. L., & Wang, C. X. (2008). Student response systems in higher education: Moving beyond linear teaching and surface learning. *Journal of Educational Technology Development and Exchange, 1*(1), 93-104.

Eisele-Dyrli, K. (2011). Mobile goes mainstream. *District Administration*. Retrieved June 9, 2013, from http://www.districtadministration.com/article/mobile-goes-mainstream.

Fisher, R., Cavanagh, J., & Bowles, A. (2011). Assisting transition to university: Using assessment as a formative learning tool. *Assessment & Evaluation in Higher Education, 36*(2), 225-237.

Flowerdew, J., & Miller, L. (1996). Lecturer perceptions, problems and strategies in second language lectures. *RELC Journal, 27*(1), 23-46.

Fogg, P. (2007). A dozen teaching tips for diverse classrooms. *The Chronicle of Higher Education*. Retrieved June 9, 2013, from http://chronicle.com/article/A-Dozen-Teaching-Tips-for/1857.

Frederick, P. J. (1986). The lively lecture—8 variations. *College Teaching, 34*(2), 43-50.

Gray, K., & Steer, D. N. (2012). Personal response systems and learning: it is the pedagogy that matters, not the technology. *Journal of College Science Teaching, 41*(5), 80-88.

Gysbers, V., Johnston, J., Hancock, D., & Denyer, G. (2011). Why do students still bother coming to lectures, when everything is available online? *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International), 19*(2), 20-36.

Harvey, L. (1999). The sense in satisfaction. *Times Higher Education*. Retrieved June 12, 2013, from http://www.timeshighereducation.co.uk/144626.article.

Hoffman, C., & Goodwin, S. (2006). A clicker for your thoughts: technology for active learning. *New Library World, 107*(9/10), 422-433.

Kenney, J. L. (2012). Getting results: small changes, big cohorts and technology. *Higher Education Research & Development, 31*(6), 873-889.

Keough, S. M. (2012). Clickers in the classroom : A review and a replication. *Journal of Management Education, 36*, 822-847.

Kitchen, E., Bell, J. D., Reeve, S., Sudweeks, R. R., & Bradshaw, W. S. (2003). Teaching cell biology in the large-enrollment classroom: methods to promote analytical thinking and assessment of their effectiveness. *Cell Biology Education, 2*(3), 180-194.

Knight, J. K., & Wood, W. B. (2005). Teaching more by lecturing less. *Cell Biology Education, 4*(4), 298-310.

Kolb, L. (2011). Adventures with cell phones. *Educational Leadership, 68*(5), 39-43.

Kumar, S. (2003). An innovative method to enhance interaction during lecture sessions. *Advances in Physiology Education, 27*(1), 20-25.

Lantz, M. E. (2010). The use of 'clickers' in the classroom: Teaching innovation or merely an amusing novelty? *Computers in Human Behavior, 26*(4), 556-561.

Marrs, K. A., & Novak, G. (2004). Just-in-time teaching in biology: creating an active learner classroom using the internet. *Cell Biology Education, 3*, 49-61.

McCune, V., & Hounsell, D. (2005). The development of students' ways of thinking and practising in three final-year biology courses. *Higher Education, 49*(3), 255-289.

McLaughlin, K., & Mandin, H. (2001). A schematic approach to diagnosing and resolving lecturalgia. *Medical Education, 35*(12), 1135-1142.

McNeill, R. G. (2011). *Adapting teaching to the millennial generation: a case study of a blended/hybrid course.* Paper presented at the International Council on Hotel, Restaurant and Institutional Education Conference, University of Massachusetts, Amherst.

Meltzer, D. E., & Manivannan, K. (2002). Transforming the lecture-hall environment: The fully interactive physics lecture. *American Journal of Physics, 70*, 639.

Méndez-Coca, D., & Slisko, J. (2013). Software Socrative and smartphones as tools for implementation of basic processes of active physics learning in classroom: An initial feasibility study with prospective teachers. *European Journal of Physics Education, 4*(2), 17-24.

Moss, K., & Crowley, M. (2011). Effective learning in science: The use of personal response systems with a wide range of audiences. *Computers & Education, 56*(1), 36-43.

Nykvist, S. S. (2012). *The trials and tribulations of a BYOD science classroom*. Paper presented at the Proceedings of the 2nd International STEM in Education Conference, Beijing Normal University, Beijing, China. Retrieved June 9, 2013, from http://stem2012.bnu.edu.cn/data/short%20paper/stem2012_78.pdf.

Powell, K. (2003). Science education: spare me the lecture. *Nature, 425*(6955), 234-236.

Ribbens, E. (2007). Why I like clicker personal response systems. *Journal of College Science Teaching, 37*(2), 60-62.

Richardson, J. T. E. (2005). Instruments for obtaining student feedback: a review of the literature. *Assessment & Evaluation in Higher Education, 30*(4), 387-415.

Robb, M., & Shellenbarger, T. (2012). Using technology to promote mobile learning: Engaging students with cell phones in the classroom. *Nurse Educator, 37*(6), 258-261.

Schell, J., Lukoff, B., & Mazur, E. (2013). Catalyzing learner engagement using cutting-edge classroom response systems in higher education. *Cutting-edge Technologies in Higher Education, 6*, 233-261.

Sharma, M. D., Khachan, J., Chan, B., & O'Byrne, J. (2005). An investigation of the effectiveness of electronic classroom communication systems in large lecture classes. *Australasian Journal of Educational Technology, 21*(2), 137-154.

Sheely, S. (2006). *Persistent technologies: Why can't we stop lecturing online.* Paper presented at the Proceedings of the 23rd annual ascilite conference: Who's learning? Whose technology?, University of Sydney, Sydney.

Stuart, J., & Rutherford, R. (1978). Medical student concentration during lectures. *The Lancet, 312*(8088), 514-516.

Taylor, C. E. (2008). Threshold concepts, troublesome knowledge and ways of thinking and practising - can we tell the difference in Biology? In R. Land, J. H. F. Meyer & J. Smith (Eds.), *Threshold Concepts in the Disciplines* (pp. 255–289). Rotterdam: Sense Publishers.

Trigwell, K., Prosser, M., Martin, E., & Ramsden, P. (2005). University teachers' experiences of change in their understanding of the subject matter they have taught. *Teaching in Higher Education, 10*(2), 251-264.

University of Queensland. (2011). Student response systems. Retrieved June 13, 2013, from http://www.elearning.uq.edu.au/content/student-response-systems.

Vicens, Q. (2013). Building students' knowledge one click at a time. *Læring og Medier (LOM), 6*(10), 1-28.

Walker, J. D., Cotner, S. H., Baepler, P. M., & Decker, M. D. (2008). A Delicate Balance: Integrating Active Learning into a Large Lecture Course. *CBE-Life Sciences Education, 7*(4), 361-367.

Watson, D. M. (2001). Pedagogy before technology: Re-thinking the relationship between ICT and teaching. *Education and Information technologies, 6*(4), 251-266.

White, N. R. (2006). Tertiary education in the Noughties: the student perspective. *Higher Education Research & Development, 25*(3), 231-246.

White, N. R. (2007). 'The customer is always right?': Student discourse about higher education in Australia. *Higher Education, 54*(4), 593-604.

Wilson, M. E. (2004). Teaching, learning, and millennial students. *New Directions for Student Services, 106*, 59-71.

Wood, W. B. (2004). Clickers: a teaching gimmick that works. *Developmental Cell, 7*(6), 796-798.