Clickers in Biosciences: Do they Improve Academic Performance?

J. Alejandro Lopez[a, b], Christopher Love[b] and Dianne Watters[b]

Corresponding Author: a.lopez@griffith.edu.au
[a]School of Natural Sciences, Griffith University, Nathan QLD 4111 and Queensland Institute of Medical Research, Herston, QLD 4006, Australia
[b]School of Natural Sciences and Eskitis Institute for Drug Discovery, Griffith University, Nathan, QLD 4111, Australia

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Abstract

While "clickers" are widely advocated for their capacity to enhance student motivation and engagement in large classes, the extent to which they lead to improved academic outcomes is a more recent target of research. The aim of this review is to analyse the literature and evaluate whether there is an improved academic performance of students in the biological and biomedical sciences as a result of using clickers. It focuses on publications in specialised peer-reviewed journals in earlier years of university and college. The evidence in the literature provides an encouraging picture of the benefit of clickers and identifies variables that may influence student academic performance. It appears that the benefit of the clickers is dependent upon the way they are used, the individuals and their prior knowledge. While there is evidence for the benefit of clickers in increasing student engagement and motivation, more needs to be done to address the scarcity of empirical and quantitative studies on their effect on academic performance.

Introduction

Clickers and other devices, based on the use of radio transmitters, are individually activated technologies (also known by several other denominations, Appendix 1), which students use to respond to prompts from lecturers allowing interactive communication in the classroom. Although originally used by TV audiences and for the teaching of physics at Massachusetts (Dufresene, Wenk, Mestre, Gerace & Leornard, 1996) and Harvard universities (Mazur, 1997) in Boston, clickers are now widely used in lecture theatres and classrooms to enhance student understanding and increase interactivity in a variety of disciplines, including biology and bio-medical sciences (Crossgrove & Curran, 2008), at multiple locations (Caldwell, 2007). There are also numerous teaching resources available to facilitate the use of clickers including; books, (Banks, 2006; Bruff, 2009; Duncan, 2006), websites such as those at Vanderbilt (Bruff, 2013), Ohio State, Georgetown, Arizona State, Loyola and Glasgow universities (Draper, 2002) and academic literature.

Studies have found that clickers can transform lecture theatres from didactic teacher-centred to interactive student-centred environments, where students are actively engaged in peer-discussion and collaborative learning, partly because of the instant feedback provided to both students and teachers. While, there is substantial literature documenting student perceptions of clickers and improvements in student motivation and engagement, evidence on whether clickers assist in improving conceptual learning is limited. Our experience confirms those

studies in the literature which provide evidence of positive student acceptance and improved student engagement in biology and biomedical courses. Whether clickers improve student conceptual understanding remains an open question. The focus of this review, therefore, is to determine whether the use of clickers can also improve student conceptual understanding.

Wide Use of Clickers

Clickers have been used across disciplines worldwide (Crossgrove & Curran, 2008). Although originating in the United States of America (USA) in the disciplines of physics and mathematics, today, clickers are used in many disciplines across entire universities (Twetten, Smith, Juliu & Murphy-Boyer, 2007) with substantial funding from the National Science Foundation (NSF) in initiatives such as CATAALYST (Classroom Aggregation Technology for Activating and Assessing Learning and Your Students' Thinking; Roschelle, Penuel & Abrahamson, 2004). University-wide implementations have been found to provide significant benefits to students when the use of clickers is mutually supported across faculties (Barnett, 2006; Hanson, Graham & Seawright, 2008; Harlow, Kushnir, Bank, Browning, Clarke, Cordon, Harrison, Ing, Kutas & Serbanescu, 2006). Although clickers were originally seen as a strategy to enhance engagement in large classes, they have been reported to be useful in other contexts, such as to develop critical thinking of students in small groups (DeBourgh, 2008), integrate active learning benefits in courses run in parallel groups (Medina, Medina, Wanzer, Wilson, Er & Britton, 2008) and identify 'at risk' students (Griff & Matter, 2008).

It has been suggested there would be an even greater uptake of clickers without the repeated technical glitches which include erratic functioning of transmitter/receivers, software dysfunction and the increased time required to prepare clicker questions for lectures (Nagy-Schadman & Desrochers, 2008). In an attempt to address these issues, Premkumar and Coupal (2008) published a helpful tool aimed at decreasing technical errors. More recently, there has been a proliferation of web-based technologies to harness mobile phones as potential replacements for clickers. These technologies can be accessed at websites such as *Poll Everywhere*, *Soapbox*, *Socrative* and *Google Moderator* (web links in reference list). Furthermore, social networking facilities such as 'Twitter' are being used instead of clickers (Paul & Iannitti, 2012). Whatever platform is chosen, successful implementation of clickers requires a focus on pedagogy.

Pedagogic Context

It has been suggested that the technology of 'clickers' facilitates constructivist and generative pedagogies in large lecture classes (Suchman, Uchiyama, Smith & Bender, 2006). Constructivists argue that learning is the result of the integration of new material with students' prior understandings (Fry, Ketteridge & Marshall, 2003). To achieve deep learning, students need to be motivated (Biggs & Tang, 2007), engage in higher order thinking (Krathwohl, 2002), and be provided with regular and appropriate feedback (Butler & Winne, 1995). Formative feedback through using clickers is just one approach that lecturers can use to support students to reflect on their comprehension of the concepts being taught (Cliff, Freeman, Hansen, Kibble & Wenderoth, 2008). Learning is also enhanced by the social context in which students 'talk' (Tanner, 2009) and build their individual understanding (Denig, 2004); clickers facilitate both processes. Clickers also provide opportunities for questioning. Questioning both consolidates and integrates learning (Wittrock, 1990). More recently, studies have found that using clickers enhances metacognition (Brady, Seli & Rosenthal, 2013) and teacher training (Finkelstein & Han, 2013).

Scope and Strategy of this Review

The aim of this review is to evaluate the value of clickers in enhancing learning in the undergraduate and college (USA) levels of education in the biological/biomedical sciences. It concentrates on the peer-reviewed literature over the last 10 years with some non-peer-reviewed reports also included. We used a systematic investigation of data bases including search engines such as PubMed™, ERIC™, Google Scholar™ and journals in the field of science teaching (Appendix 2). Keywords used in the search included 'academic', 'performance', 'outcome' AND each of the common names used for clickers (Appendix 1).

This literature review yielded somewhat contradictory results. Some of the research found that clickers resulted in a positive learning gain (as measured by improved marks on examinations and/or reduced failure rate), while other studies found no learning gain. Other studies found the benefit of clickers to be dependent on specific factors, such as prior academic performance or gender. We also included in the literature review situations where clickers were used in small groups to promote peer-discussion, often in postgraduate education.

Clickers Improve Academic Outcomes

Overall clickers are widely perceived as improving student learning, confidence (Nagy-Schadman & Desrochers, 2008) and engagement (Carini et al. 2006). This is greatly facilitated by the interactive inputs from both students and lecturers (Fies & Marshall, 2006). One main use of clickers has been in formative evaluation (Paschal, 2002). There is evidence, however, that clickers lose their novel appeal when used for summative evaluation (Suchman et al., 2006). On the other hand, the evidence for clickers being responsible for learning gain, as measured by academic performance, is still not widely accepted (Stewart & Stewart, 2013).

Grades in Exams

Student performance in exams can be a proxy for learning gain. To collect robust evidence for clickers as a tool for learning gain requires intra-cohort evaluation which compares the learning gain of students using and not using clickers. A demand to organise such designs is required to determine the effectiveness of clickers. Some studies use inter-cohort evaluation to measure learning gain. In these types of studies academic performance of cohorts of students exposed to clickers are compared to cohorts of students taught the same course at other times.

Intra-Cohort Evaluation

Preszler and colleagues (2007) investigated the effect of clickers on the learning gain of a large group of students (over 800) enrolled in six non-major biology subjects. A variable number of clicker questions were used for different components of the course and the academic performance for sections taught with low, medium or high number of clicker questions was measured on the final exam. Student performance was greater among those sections with greater clicker use and this was more pronounced in the lower divisions (Prezler, Dawe, Shuster & Shuster, 2007).

Crossgrove and Curran (2008) evaluated whether student performance in the final exam differed depending on whether students used clickers in major (genetics) and non-major biology subjects. Overall student performance was greater on exam questions taught via clickers, the effect being larger for students in non-major biology subjects. Interestingly,

when the same concepts were assessed four months after the final exam, student understanding was significantly greater on concepts where clickers had been used and in non-major compared to major courses. Some caution, however, is required in generalising this finding because of the low number of participants (14/15 of 250), and the selection of the questions, which were 'lower-order' in the non-majors exams.

In a controlled study of 175 second year physiology students at Melbourne University, Gauci, Dantas, Williams and Kemm (2009) found that students with poorer performance in a pre-requisite (physiology) course benefited most from the use of clickers. When students were grouped according to their prior grades in the previous year, those students who started the course with a history of low grades and used clickers, performed significantly better than those students who did not use clickers in lectures. In addition, the cohort obtained higher marks than historical controls where the clickers had not been used (Gauci et al. 2009).

Experiments to provide evidence that clickers enhance learning are difficult to design, from an ethical perspective. For example, Suchman et al. (2006) compared exam performance between two cohorts of microbiology students. One group was provided questions only at the start of the lecture, while the other group was taught with clickers throughout the lecture. The group which used clickers throughout the lecture obtained better exam marks and there was correlation between the differences in the grades and the extent of clicker use. This result probably reflects the fact that the lecturer was more aware of the limitations of the students from their continuous feedback and was able to change his/her lecture style accordingly. The main outcome of this study was that students in the group with high clicker use had an increased confidence, which probably also influenced their academic performance.

Levesque (2011) also found that genetics students who used clickers had improved capacity for solving problems during exams. The number of clicker questions was positively correlated with exam performance. The greater the exposure to clicker questions, the more improved the grade. Further, this improvement was not dependent on whether the questions were correctly answered. Instead, it appears that when students are exposed to problems via clickers and peer-discussion, deeper learning occurs, which is transferred to the ability to solve novel problems in exam settings (Levesque, 2011).

The effect of clickers on academic performance of dentistry freshman students was also evaluated using a cross-over trial design (Elashvili, Denehy, Dawson, & Cunningham, 2008). Students (n=77) were randomly allocated into two groups who each received the same lecture material (same lecturer and on the same day). One group received the content in a lecture format using clickers, while the other group received the content in a conventional lecture format. Overall the academic performance of students in lectures where clickers were used was greater on a post-test evaluation and they performed better in a lower complexity psychomotor skill assessment than students in lectures where there were no clickers. There was, however, no difference between the groups in the final exam.

In another study the academic performance of pharmacology students was tracked over four successive cohorts (Mostyn, Meade & Lymn, 2012). Students in all cohorts used clickers and were given regular and individual feedback on questions. There was a significant positive correlation between formative feedback scores and student performance in the final exam, tracked over two years. A significant positive correlation was also found between clicker responses and student performance in the final exam in a dental biochemistry course (Levine, 2011). Similar results were reported for students in anatomy classes (Alexander, Crescini,

Juskewitch, Lachman, & Pawlina, 2009). These studies did not, however, examine the benefit of clickers compared to not using them.

Inter-cohort Evaluation

There are several studies in the literature which also aim to determine the effectiveness of clickers using inter-cohort evaluation. Inter-cohort evaluations do not control for the variability among cohorts which makes the interpretation of the data more difficult. In an inter-cohort evaluation, instead of analysing teaching approaches in the same cohort of students, the academic performance of current cohorts is compared to previous years. Overall these studies have found positive impacts of clickers on student learning. Pharmacology students performed better in the final exam, in particular in analytical questions when clickers were used (Slain, Abate, Hodges, Stamatakis & Wolak, 2004). Similarly, Biology students at college level obtained 8% higher grades than the cohorts from two previous years when taught with clickers (Ribbens 2007). Studies on Medical students also reported that retention of knowledge in anatomy and physiology subjects was higher than retention following conventional didactic lectures (Carpenter & Boh, 2008; Sawdon, 2009). While encouraging, the lack of appropriate controls in these studies prevents definitive conclusions on the impact of clickers on academic performance.

In addition, various non-peer reviewed reports identify beneficial effects of the use of clickers. In a cohort of 650 biology students, clickers influenced the study strategy of students with the use of clickers correlated with student performance in exams (Dawson, Meadows, & Haffie, 2010). In other studies, academic performance of students in biology and radiology increased up to 5% in final exams when clickers were used (El Radi, 2006; Lorimer & Hilliard, 2008).

Reduced Failure Rate

Lower failure rates have also been reported when clickers were used in an introductory biology course (Knight & Wood, 2005), perhaps because of the more interactive nature of lectures. For students at risk, the interaction which results from clickers reduced the failure rate compared to students answering questions using cards (Freeman, O'Connor, Parks, Cunningham, Hurley, Haak, Dirks & Wenderoth, 2007).

Clickers do not improve Academic Outcomes

There have also been several studies which have found no learning gain from clickers. Bunce VandenPlas and Havanki (2006) compared the learning gain (as measured by exam performance) in biology subjects who did, and did not use clickers. Although there was a trend for better academic performance in the subjects taught with clickers, the difference was not statistically significant. Sutherlin, Sutherlin, and Akpanudo (2013) used a 'switching' experimental design to investigate the extent to which the use of clickers predicted learning gain after consideration of factors such as student Grade Point Average (GPA), the number of hours of study which students reported and prior academic performance. They found no evidence that clickers predicted student achievement. Instead, GPA and prior academic performance were better predictors of academic achievement. This was even in a context where students perceived a positive learning gain from clickers. Stoddard and Piquette (2010) also employed a 'switching' design and found no significant difference in exam performance between control and experimental groups. The authors concluded that the improved academic performance found in other studies may have been because of questions embedded in

lectures, rather than clickers alone. These studies collectively provide evidence that clickers improve the student experience, but may have little impact on final academic performance.
Further evidence of a lack of improvement of clickers on academic performance includes a randomised study of 5th year medical students (Duggan, 2007). In two consecutive clinical topics, ovarian and breast cancer, students were divided into two groups. In the first group, students attended lectures in a traditional mode (i.e. lectures) for the first topic and clickers were used in the second topic. In the second group, clickers were used for the first topic and lectures were delivered on the second topic. Student understanding was assessed before and after the two consecutive clinical topics and eight weeks later. There was no difference in student understanding in the pre-test evaluation, nor in any of the later evaluations. It was suggested that the lack of correlation between clickers and academic performance was that students in 'upper divisions' (later in their courses) may benefit less from clickers (Preszler et al, 2007) and that clickers may be effective in the retention of concepts, but not in development of skills in clinical analysis (Crossgrove & Curran, 2008).

Other studies comparing academic performance of cohorts in parallel have also failed to detect any benefit of clickers. There was no difference in the academic performance between two small groups (20) of veterinary medicine students, in an intensive elective course, taught by the same lecturer with and without clickers (Plant, 2007). Academic performance on assessments and retention of concepts was similar in both groups. There was no difference in the learning gain in nursing (Patterson, Kilpatrick, & Woebkenberg, 2010), neurophysiology (Paschal, 2002) or dental material (Barbour, 2008) when clickers were used and compared to the performance of previous cohorts.

Effect of prior academic performance

One major variable of the effect of clickers on academic performance is that differences in the academic profile of students are not factored into evaluations. It is possible that students with prior academic success, who are more engaged with learning, are also more likely to engage with a new technology. Knight and Wood (2005) factored into their design the previous academic performance of a cohort of final year developmental biology students and compared this to the previous performance of two cohorts. They found that students' with better prior academic results had an enhanced benefit from learning within the interactive environment provided by clickers. (Knight & Wood, 2005). There were no differences according to ethnicity or gender in their study.

A similar finding was reported for students in an introductory biochemistry class (Addison, Wright & Milner, 2009). A group of students were given the opportunity to use clickers for a segment of the course, while other groups did not use clickers at all. Overall, there was no difference in academic performance of students in the final exam taught with or without clickers compared to historical controls. There were, however, significantly more students who had used clickers in the higher performing rank (> 91-100 category). This study suggests that either high achieving students benefit more from clickers than the remainder of the cohort or that there is no benefit from using the clickers. One explanation maybe the greater self-confidence of students who are high achievers, as self-reported. Alternatively, the results may reflect student attitude towards learning. Indeed, there was a very good positive correlation between academic performance and attitude towards clickers. Students in the lower categories of academic performance did not find clickers helpful in performance (Addison et al. 2009).

In contrast to these two studies, and as referred to earlier, Freeman et al. (2007) identified a greater benefit from clickers for students 'at risk' in an introductory Biology course. Similarly, students with a history of poor academic performance appeared to benefit more from clickers (Gauci et al. 2009).

Clickers Benefit Certain Groups of Students

The effect of Gender

Some studies provide evidence that gender may be a factor in the response of students towards clickers. Females students in several cohorts of engineering students engaged more with clickers than males (King & Joshi, 2008), although in the groups which used clickers the overall academic performance of males was greater than females in the final exam. It is, however, difficult to establish a definitive explanation in this study due to bias with a large number of male compared to female students. Indeed, this finding contradicts a study on the benefit of clickers in a physics course where clickers reduced the gap in academic performance between male and female students (Reay, Li & Bao, 2008). Both studies conclude that more females than males use clickers. Differences in the effect of clickers on academic performance and gender have also been found in large biology case studies (Kang, Lundeberg, Wolter, DelMas & Herreid, 2013). Comparing marks at the end of the course, women were found to have greater academic performance on content taught by clickers and more positive attitudes than men towards clickers, whereas men learned more effectively from PowerPoint lectures. The authors stated that this was because females engaged emotionally with clickers and engaged less with factual PowerPoint presentations.

Small groups

Clickers have also been used in small group discussions. There was a statistically significant improvement in the exam performance of first year medical subjects taught to small groups (13-21 students) via clickers compared to groups in a classical setting for two separate subjects (abdominal pain and abdominal haemorrhage), They were tested before and after the class, and 6 weeks after completing the course. One group in South Australia reported that the use of clickers enhanced long-term retention (Palmer, Devitt, DeYoung & Morris, 2005).

Post-graduate learning

Clickers have also been used in post-graduate training of medical specialists (Cain & Robinson, 2008). The beneficial effect of clickers was reported in the training of specialists in family medicine. In this switching, randomised study, two groups of 8-15 students received eight pairs of lectures with and without the use of clickers (Schachow, Chavez, Loya & Friedmann, 2004). There was better post-test performance and long-term (1 month) retention of content by students when clickers were used. Similar results were reported for a radiologist training course (Rubio, Bassignani, White & Brant, 2008). It has been suggested that one benefit of clickers is that responses of students can be collected anonymously. The increased student participation occurred because of decreased fear of being identified. One study with graduate students, which examined the impact of anonymous versus the assigned use of clickers on student achievement, however, found no difference in academic performance of students (Poole, 2012). The results of that study suggested that tracking student performance does not affect overall performance. Further work is required to determine if the results are replicated with undergraduate students. It is also worth noting that students resent the use of clickers when their participation is graded (Suchman et al. 2006).

The Benefit of Peer-Discussion

One of the key pedagogic values of the clickers is the increased discussion which occurs with peers, enhancing and strengthening student understanding which is likely to improve academic performance (Mazur, 1997). Smith, Wood, Adams, Wieman, Knight, Guild and Su, (2009) who investigated the benefit of peer-discussion following clicker questions in the process of learning, found the rate of correct responses improved after peer discussion, even when no member of the group initially knew the correct answer. Using a questionnaire of perceived benefit in learning and interactivity, 198 undergraduate business students concluded that the use of clickers facilitated interactivity with peers and with the teacher which, in turn, improved learning performance (Blasco-Arcas, Buil, Hernandez-Ortega & Sese, 2013). Interestingly, clickers can also stimulate peer discussion when used to disseminate science to a non-scientific audience (Smith, Annis, Kaplan & Drummond, 2012).

Peer discussion and audience response systems can also assist with the challenges of teaching large bioscience classes by promoting active student participation. In a large class of nursing students, it was found that clicker technology used anonymously for formative assessment, increased participation and peer discussion, and assisted with the identification of student misconceptions, however it did not motivate students to study adequately before attending the sessions (Efstathiou & Bailey 2012). This is an important consideration with the push to provide more 'blended learning' opportunities, i.e. flipped classrooms with online lectures giving time for more productive use of class time for problem solving and discussion of concepts (Prunuske et al. 2012).

A Glance at Clickers in other Disciplines

While not the main objective of this review, in our search we also identified publications in the literature on the effect of clickers on learning in other science disciplines. Overall these studies find a beneficial effect. Peer reviewed publications in the disciplines of psychology (Morling, McAuliffe, Cohen, & Dilorenzo, 2008), physics (Sharma, Khachan, Chan & O'Byrne, 2005) and management (Yourstone, Kraye & Albaum, 2008), report a small benefit in academic performance in final exams. There was also a difference of 21% in academic performance of students when they answered questions on concepts which had been taught with clickers in psychology (Shapire, 2009). Similar encouraging results appear in non-peer-reviewed reports also in psychology (Mayer, Stull, DeLeeuw, Almeroth, Bimber, Chun Bulger, Campbell, Knight & Zhang 2009) and outside science in the discipline of commerce (Nguyen, Fraunholz, Salzman & Smith, 2006). More recently, Deslauriers, Schelew and Wieman (2011) compared the learning of two sections on electromagnetic waves in a large introductory physics class under different instructional approaches. The first section was taught by an experienced lecturer in the traditional fashion, and the second section was taught by two inexperienced instructors using clickers, peer discussion, small-group active learning tasks and instructor feedback. A test on the content administered to both groups was conducted at the conclusion of the unit. The result, with no overlap in the distribution of test results between the two groups, provided evidence of a learning gain for the groups which were taught using more interactive methods including clickers. The study can be criticised, however, for the lack of randomisation and appropriate controls (Derting, Williams, Momsen & Henkel, 2011; Torgerson, 2011). On the other hand, a report on the teaching of geography found no learning gain when clickers were used (Czekanski & Roux, 2009).

Bojinova and Oigara (2011) compared exam results in a *Principles in Microeconomics* course, where one section of the course was taught with clickers and the other section

without. In the final exam results there was no significant difference in academic performance of students between sections taught using clickers versus traditional methods. A further study by Oigara and Keengwe (2013) in a small, physical geography class found clickers promoted student engagement with 95% of students indicating they were more likely to answer questions in lectures where clickers were used as opposed to raising their hand. Only 45% reported, however, that they were inspired to increase the amount of time spent on study. Gray and Steer (2012) investigated whether clickers used in conjunction with lecture tutorials improved student learning compared with lecture tutorials alone. In the lecture tutorials students were given paper-based conceptual questions for peer discussion. Their results show that the pedagogy and not the technology *per se* was more important in improving learning, with no significant improvement in academic performance of students who used clickers. Martyn (2007) also found no difference in student learning outcomes for students in computer literacy classes taught with clickers compared to class discussion. Blasco-Arcas et al. (2013) proposed that clickers promotes interactivity with peers and with the teacher, which in turn promotes active collaborative learning and engagement and stated that it was the improved interaction which ultimately leads to enhanced performance. Similarly, Bruff (2009) suggested that the way in which clickers are incorporated into the classroom instruction, rather than clicker use *per se*, influences learning outcomes.

Conclusions

The overwhelming evidence that clickers promote student engagement in formative assessment on its own justifies the wide use of clickers in teaching (Beatty & Gerace, 2009; Kay & LeSage, 2009). Best practice involves connecting the clickers to learning objectives and engaging students with clicker questions though peer to peer and lecturer to peer discussion. Barbour (2013) provides strategies for doing this. Clickers can support and augment existing principles of good teaching. Hoekstra and Mollborn (2012) show how clickers can be used to promote active learning in large classes. They provide five principles of effective use of clickers including: (i) gathering student feedback to promote teaching and learning; (ii) identifying student assumptions or preconceptions about course material, (iii) supporting conceptual application and critical thinking through small- and large-group discussions, (iv) fostering social cohesion in the learning community and collecting data from students to support theory testing, and (v) conceptual application and group discussion. Stewart and Stewart (2013), discuss a teaching model which is flexible, contingent to students' needs and makes use of students' feedback via clickers. It is, however, not straightforward to transform the didactic lecture and transmissive classroom with clickers. To implement clickers successfully so that there is an improvement in the academic performance of students requires adjustments of pedagogy over time (Kolikant, Drane & Calkins, 2010).

The issue of gathering reliable and robust evidence of the benefit of clickers in improving academic performance is more complex. From the literature reviewed here, the results are encouraging. Overall there appears to be evidence that clickers assist students to learn concepts, particularly in the earlier years of tertiary education. The jury is still out on the benefits of their use for more analytical tasks and in post graduate courses in the later years of study. It appears also, that the effectiveness of clickers may depend on the discipline. There are several variables that influence the veracity of the evidence including the choice of the appropriate control. While inter-cohort studies give an indication of how cohorts may behave, year to year variation among cohorts can be significant. More cross-over and switching studies are now appearing in the literature and have the potential to be more reliable. It is

important in all studies to appropriately randomise students within the study groups. It appears that the main gain in academic performance of students from the use of clickers is related to the increased interaction between lecturers and students. Measuring this interaction should be the focus of the attention of future studies on the benefits of clickers (Martyn, 2007).

The shortage of rigorous evaluation of technology on learning outcomes is a limitation observed in the evaluation of other innovations in the classroom. A recent review of 868 studies implementing new technologies for undergraduate science cohorts concluded that, often, they lack robustness and that it is difficult to draw firm conclusions due to the absence of rigorous, scientific, quantifiable approaches (Ruiz-Primo, Briggs, Iverson, Talbot & Shepard, 2011). At this point where the technology of clickers is well advanced and widely used, more detailed evaluations controlling for the variables described in this review and specifically targeting the impact of clickers on learning gain should be the focus of studies in the future.

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Appendix 1. Names under which 'clickers' are known

Given Name	Reference
Clickers	(Wood, 2004)
KEEpad™	(Sawdon, 2009)
Electronic Voting System	(Draper, 2002)
Audience Response System	(Caldwell et al., 2007)
Classroom Response System	(Draper, 2002)
Group Response System	(Draper, 2002)
Interactive Response System	(Slain et al., 2004)
Interactive Voting System	(Brezis & Cohen, 2004)
Student Response System	(Preszler et al., 2007)
Synchronous Electronic Polling Equipment	(Draper, 2002)

Appendix 2. Sources searched for the literature review

Source	**Producer**	**URL**
Biochemistry and Molecular Biology Education	Wiley Interscience	www.iubmb.org/index.php?id=30
CBE Life Science Education	American Society for Cell Biology	www.lifescied.org
Classroom Response System ("Clickers") Bibliography	Vanderbilt Center for Teaching, Vanderbilt University	http://cft.vanderbilt.edu/docs/classroom-response-system-clickers-bibliography/#bio
Eric (Education Resources Information Center)	Institute of Education Sciences	www.eric.ed.gov
Google Scholar	Google ™	www.scholar.google.com
International Journal of Science Education	Francis & Taylor	www.tandf.co.uk/journals/tf/09500693.html
International Journal of Science and Mathematics	Springer	www.springer.com/education/mathematics+education/journal/10763
Journal of Biological Education	Institute of Biology	http://www.tandfonline.com/action/journalInformation?journalCode=rjbe20#.UftLSG3cPoU
Journal of Research in Science Teaching	Wiley InterScience	www.interscience.wiley.com/journal/31817/home
Research in Science Education	Springer Link	www.springerlink.com/content/108230
PubMed	US National Library of Medicine	http://www.ncbi.nlm.nih.gov/pubmed/