Using a personal response system as an in-class assessment tool in the teaching of basic college chemistry

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Since the introduction of personal response systems (PRS) (also referred to as "clickers") nearly a decade ago, their use has been extensively adopted on college campuses, and they are particularly popular with lecturers of large classes. Available evidence supports that PRS offers a promising avenue for future developments in pedagogy, although findings on the advantages of its effective use related to improving or enhancing student learning remain inconclusive. This study examines the degree to which students perceive that using PRS in class as an assessment tool effects their understanding of course content, engagement in classroom learning, and test preparation. Multiple, student-performance evaluation data was used to explore correlations between student perceptions of PRS and their actual learning outcomes. This paper presents the learning experiences of 151 undergraduate students taking basic chemistry classes and incorporating PRS as an in-class assessment tool at the National Chung Hsing University in Taiwan. While the research revealed positive student perceived benefits and effectiveness of PRS use, it also indicated the need for further studies to discover what specific contribution PRS can make to certain learning outcomes of a large chemistry class in higher education.

Introduction

The development of interactive technology, such as SMART Boards and clickers, in classroom teaching is one of the fastest growing dimensions of both the information technology industry and education at all levels (Ward & Benson, 2010). Personal Response Systems (PRS) or Audience Response Systems (ARS), frequently called "clickers" are now enjoying widespread success within higher education as a teaching tool (Abrahamson, 2006; Burnstein & Lederman, 2006). Evidence of the pedagogical value of PRS continues to accumulate, with competition among manufacturers driving technical improvements. With an increase in user-friendliness and decreased prices, PRS use is growing rapidly in large science courses at the university level (Caldwell, 2007; Crossgrove & Curran, 2008). Although faculty are encouraged to use PRS in classroom teaching, sufficient evidence of positive student perception varies when it is applied by different pedagogical strategies as an aid to student learning and increased interest. Kay and LeSage (2009) indicated that research concerning PRS as beneficial or suitable for summative assessment is lacking, implying that different attempts to use it possibly leads to variance in its effectiveness to promote classroom learning. Students may also see PRS differently when employed as a fun teaching tool possessing novel elements compared to a tool for serious assessment. This possibility suggests that it is risky to equate the positive effects of one application with another.

Classroom instructional assessments are often viewed as formative assessments, and differ from the learning outcome or summative evaluation typically used for grading purposes. Compared to the paper-based formative assessment in class, PRS is well suited to supporting the assessment features of data collection, analysis, and teacher and student feedback. Hancock (2010) showed PRS greatly improves the burden, cost, security, and validity of paper tests in a large class. Numerous studies have demonstrated its effectiveness in enhancing student learning in a lecture class (Caldwell, 2007; Crossgrove & Curran, 2008; Preszler, Dawe, Shuster, & Shuster, 2007). However, studies examining student views of PRS as an in-class assessment tool for both formative and summative purposes and its effect on student grades and learning outcomes are scant. This study explores student perceptions on the use of PRS as an in-class assessment tool and its relationship with student academic performance in a large introductory chemistry course at the National Chung Hsing University of Taiwan.

Literature Review

Interactive technology such as PRS (also referred to as Audience Response Technology, Student Response System, Electronic Voting System, and "clickers") has been viewed positively by students and instructors in numerous studies, particularly in the Science, Technology, Engineering, and Mathematics (STEM) disciplines (MacGeorge et al., 2008). Instructors across varied disciplines are realizing the pedagogical value of these systems, including greater student engagement with lecture content, interactive participation in presentations, increased student understanding of and motivation toward learning course material, higher class attendance, enhanced subject interest, and improved examination performance (Preszler et al., 2007). PRS is widely used to promote interactivity, gather feedback, pre-assess knowledge, and assess student understanding of lectured concepts. It is considered valuable for supporting instructional activities in large classes, such as recording attendance, polling to create initial interest among students, promoting critical thinking and active learning, incorporating problem-based learning, and community building and the initiation of discussion. Teacher responses to class application of PRS reveal a positive attitude, and a willingness to continue its use (Stuart, Brown, & Draper, 2004; Blackman, Dooley, Kuchinski, & Chapman, 2002; Barnett, 2006).

A review of literature on the effects of using PRS in higher education suggests generally positive outcomes and effects on student learning (Caldwell, 2007; Crossgrove & Curran, 2008; Eilks & Byers, 2010; Fies & Marshall, 2006; Hoffman & Goodwin, 2006; Judson & Sawada, 2002; Preszler et al., 2007). Research shows that student reaction includes ease of use with enhanced classroom engagement and a positive influence on attention, interest, and involvement while learning (Copas & Del Valle, 2004; Fitch, 2004; Hall, Collier, Thomas, & Hilgers, 2005; Latessa & Mouw, 2005; Reay, Li, & Bao, 2008; Rice & Bunz, 2006; Sharma, Khachan, Chan, & O'Byrne, 2005). Students and faculty consistently indicate a positive view of PRS, particularly to perceived improvement in attendance, engagement, and motivation (Hansen, 2007). Content reinforcement, feedback, anonymity in participation, increased interest in the course, and the ability to compare one's knowledge level to that of the rest of the class have all been reported as benefits of PRS. However, numerous perceived learning benefits remain inconclusive (MacGeorge et al., 2008).

Considering a failure to distinguish PRS use as a pedagogy rather than a tool, research is strengthened by the diverse pedagogical approaches and the effect on learning of those various approaches (Beatty & Gerace, 2009; Fies & Marshall, 2006). Unfortunately, little work has been done in response to this (Beatty & Gerace, 2009). In this paper, the use of PRS in a large introductory chemistry class was specifically designed to be an in-class assessment tool to periodically examine student learning of course content throughout the semester. Differing from research treating PRS use as either formative (Asirvatham, 2005; Bunce, VandenPlas, & Havanki, 2006; Filer, 2010) or summative (Hancock, 2010; Mula & Kavanagh, 2009) assessment, this study is relatively unique as it applies both approaches from a pedagogical standpoint.

Research Method

The Research Context

The two courses examined in this study were General Chemistry taught by the same instructor mainly via lectures. The study was completed over 18 weeks, with 15 weeks for lectures and three weeks for exams. Of the 15 lecture classes, five included a laboratory session. The lab experiences helped motivate student interest in learning abstract chemistry concepts by involving them in observation and experimentation. The examination period comprised the pre-class chemistry proficiency test in the first week and the midterm and final tests held in the 9th and 18th weeks respectively. The final student learning outcomes were determined by their semester course grades which included their paper-based midterm and final test scores, weekly online homework, and in-class tests using PRS.

As an in-class assessment tool, PRS enables students to obtain immediate performance feedback after submitting their responses. It can also assist instructors by receiving and analysing student responses to lecture questions. In this study, PRS was used primarily to deliver individual electronic ConcepTest questions. ConcepTest questions are available for a wide range of disciplines including chemistry (Butcher, Brandt, Norgaard, Atterhol, & Salido, 2003; Asirvatham, 2005). The mean, concept-based multiple-choice questions required students to apply their understanding of underlying concepts to determine the correct answers (Crouch & Mazur, 2001; Mollborn & Hoekstra, 2010). The factual, ConcepTest questions served as a check to determine whether students had mastered the content. All multiple-choice questions in this study were collaboratively developed by the instructor and teaching assistant and presented at strategic points throughout the lecture.

Ten quizzes using PRS were given periodically throughout the semester. Each consisted of 10 to 15 review questions which then helped to identify areas in need of further work. They were projected onto the screen giving students 2-3 minutes to respond by pressing the appropriate key on their handheld, wireless remote device which held a unique ID to enable individual scoring. The teaching assistant and instructor monitored time via the display for the number of responses clicked. With the display of correct responses colour highlighted, including a histogram (percentage of responses versus response A, B, C, or D) at the end of each test, all other data was retrieved and stored for further analysis.

At the end of testing, by way of formative assessment, the instructor displayed the questions and the correct answers and offered an opportunity for immediate discussion and clarification. The instant feedback generated by PRS, allowed the instructor to provide explanation if quizzes were administrated during class, or students could review their understanding via testing at the end of class. At the next session, the instructor was then equipped to clarify questions, deficiencies, or misunderstandings of learning content depending on prior student performance. Each PRS test result contributed to part of the course grade. The PRS functioned as a checkpoint of student learning throughout the course. In this case, use of PRS as an in-class assessment tool combined the formative and summative approaches. With the aid of the student perception survey conducted at the end of the semester, this study examined the degree to which students perceive the use of PRS in class affects their understanding of the course content, engagement in classroom learning, and test preparation. Data derived from different learning assessments, including a pre-class chemistry proficiency test and online homework scores, midterm, and final test scores, PRS test score, and semester grades, was used to identify any correlations between student perception of PRS and their learning performance.

Research Subjects

Evaluating the use of PRS as an in-class assessment tool to supplement traditional face-to-face classroom instruction, the survey data was used to examine student perceptions of PRS used in this way as an alternative to conventional paper-based tests. This study was conducted in 2008 when PRS was first introduced to the target university, with the surveyed students having had no prior experience of using PRS in college courses. In total, 151 students participated in the questionnaire survey on perceptions of PRS usage; 61.1% of the participants were men, and nearly all were first year students. Of the survey participants, 56.3% were from the College of Agriculture and Natural Resources, and 31.1% were students in engineering disciplines.

Research Instrument

The student-perception survey instrument included six quantitative items (Table 1). Student feedback via an informal interview conducted near the middle of the semester had an overall Cronbach's alpha coefficient of .933, which is considered highly acceptable. To achieve instrument validity, the questionnaire development process included a systematic review of related literature combined with student feedback of their learning experience with PRS. The course professor and two instructional design professionals helped to round off the validation process. All six items were rated on a 4 point Likert-like scale, from "strongly agree (1)" to "strongly disagree (4)." In addition to the perception survey, student performance data were analysed, including pre-class chemistry proficiency test scores, weekly online homework grades, midterm and final exam scores, in-class PRS test scores, and semester grades.

Data Analysis

Statistical analysis was conducted using the Statistical Package for Social Science for Windows 15.0 (SPSS 15.0). Data analysis included: (1) descriptive statistics, used to describe student perceptions of PRS use and learning performance of the respondents; (2) correlation and mean comparison analyses, to determine the relationships between student perceptions of PRS use and learning performance.

Findings and Discussion

Student Perceptions of PRS Use and Learning Performance

Based on the results in Table 1, student perceptions of PRS as an in-class assessment tool tend to be positive. This finding corroborates the research results of Caldwell (2007), Crossgrove and Curran (2008), Eilks and Byers (2010), Fies and Marshall (2006), Hoffman and Goodwin (2006), Judson and Sawada (2002), and Preszler et al. (2007). However, the results also reveal that students experienced an inability to decipher and think clearly while taking the quiz. Nearly half (49%) of the students reported this phenomenon when undergoing the PRS test. A study by Gray, Owens, and Liang (2012) confirmed that the way the PRS question is written or presented has no influence on how students respond; so, the presentation of questions can be excluded. The primary cause of this problem may be the lack of flexibility and autonomy when answering, and the time constraints or peer pressure to reply correctly. Greater effort to determine the exact causes of this problem and its pedagogical disadvantages is necessary to develop a PRS with an enhanced learner-centred instructional design.

Table 1
Survey of student perceptions of PRS use (n=151)

	Question	Agreed (%)	Disagreed (%)	Mean (SD)
1	Using PRS as a test tool in this course was easy.	74.2	25.8	2.16 (0.83)
2	Using PRS as a test tool in this course interfered with my ability to think clearly while taking the test.	49.0	51.0	1.96 (0.83)
3	Using PRS as a test tool in this course increased my engagement in classroom learning.	57.0	43.0	2.38 (0.85)
4	Using PRS as a test tool in this course was fun.	68.9	31.1	2.25 (0.82)
5	Using PRS as a test tool in this course benefited my chemistry learning.	66.9	33.1	2.29 (0.79)
6	Using PRS as a test tool in this course enhanced my learning effectiveness.	60.3	39.7	2.35 (0.79)

Note. The response to each question is measured using a Likert scale: 1=strongly agree, 2=agree, 3=disagree, and 4=strongly disagree. The mean is the average response value, and SD is the standard deviation. A total of 151 students participated in the survey. 'Agreed %' is calculated from the number of students who responded 'agree' or 'strongly agree'. 'Disagreed %' is calculated from the number of students who responded 'disagree' or 'strongly disagree'

Student performance data were also collected for analysis. The grade scores of multiple learning outcome assessments conducted on the courses examined by this study are shown in Table 2.

Table 2
Mean and standard deviation of student performance assessment scores (n=151)

Student performance variable	**Mean**	**SD**
Pre-class chemistry proficiency test	47.75	9.07
Online homework	47.07	36.99
Midterm exam	74.91	14.98
Final exam	48.28	13.06
In-class PRS test	49.42	17.86
Semester course grade	62.66	15.29

Correlation between Student Perceptions of PRS Use and Learning Performance

As shown in Table 3, student scores from the pre-class chemistry proficiency test showed a significant correlation between the scores of weekly online homework ($\gamma = .37$), midterm exams ($\gamma = .34$) and semester course grades ($\gamma = .44$) using $p < .01$ Pearson correlation analysis. There was a significant correlation between the in-class PRS scores and those of the midterm exams ($\gamma = .51$), final exams ($\gamma = .71$), weekly online homework ($\gamma = .56$), and semester course grades ($\gamma = .58$) using $p < .01$ Pearson correlation analysis. In summary, most student-performance scores significantly correlated with each other.

Table 3
Correlation between student performance and perceptions of PRS use in class

Student perception of PRS	**Student performance**											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ease of use(1)	1	.60**	.15	.56**	.58**	.56**	.03	-.02	-.10	-.00	-.16*	-.09
Fun(2)		1	.09	.59**	.73**	.65**	.01	.05	-.08	.07	-.07	-.05
Interference during tests(3)			1	.21**	.17*	.15	-.02	.12	.10	.17*	.08	.06
Learning engagement(4)				1	.68**	.75**	.06	.08	-.01	.09	-.04	.01
Beneficial to learning(5)					1	.82**	.01	-.02	-.11	-.00	-.20*	-.09
Learning effectiveness(6)						1	.04	.03	-.05	.06	-.15	-.14
Pre-class chemistry proficiency(7)							1	.44**	.37**	.34**	-.02	.13
Semester course grade(8)								1	.66**	.76**	.54**	.58**
Grade of online homework(9)									1	.63**	.59**	.56**
Grade of midterm exam(10)										1	.48**	.51**
Grade of final exam(11)											1	.71**
Grade of in-class PRS test(12)												1

Note. * $p < .05$; ** $p < .01$

As shown in the results listed in Tables 1 and 3, student perceptions of PRS as an in-class assessment tool are primarily positive. However, nearly half of the respondents also perceived that it interfered with their ability to think clearly while taking tests. The perception of ease of use correlates significantly to the other four perception measures using $p < .01$ Pearson correlation analysis, excluding the perception of interference during test taking.

As there appeared to be a perception that PRS was intrusive under test conditions, we tested this assumption with a t-test in addition to correlation analysis. Student perceptions of the ease of use and the benefits to learning showed a clear correlation to their final exam scores with $\gamma=-.16$ and $\gamma=-.20$ ($p < .05$). The interference perception during test taking showed a clear correlation to their midterm exam scores ($\gamma=.17$, $p < .05$). Additionally, the t-tests confirmed that students who agreed that PRS increased their engagement in classroom learning had significantly higher weekly online homework scores than the group who disagreed ($t=2.22$, $p < .05$). Students who agreed that PRS use benefited their learning had significantly higher final exam scores than those of the group who disagreed ($t=3.70$, $p < .001$). Students who agreed that PRS use enhanced their learning effectiveness had significantly higher weekly online homework ($t=3.66$, $p < .001$) and in-class PRS test ($t=2.02$, $p < .05$) scores than those in the group who disagreed. As for the relationship between student perceptions of PRS and their semester grade, this study concluded that students who agreed that PRS use benefited their learning ($t=3.09$, $p < .01$) and enhanced their learning effectiveness ($t=2.56$, $p < .05$) had significantly higher semester grades than the group who disagreed. Therefore, this study identified certain interactions between student perceptions of PRS as an in-class assessment tool and their learning performance. Significant relationships particularly emerge when students perceive PRS use to positively affect their learning, such as benefitting their understanding or increasing their learning effectiveness.

Conclusions and Implications

Numerous university instructors worldwide have recently used interactive technologies, such as PRS or "clickers" to enhance classroom teaching and learning, particularly in large enrolment, introductory STEM classes. This study adopted PRS as an in-class assessment tool to understand its effects on student learning of basic chemistry in higher education. The findings of this study increase existing knowledge of PRS benefits and possible disadvantages for traditional undergraduate learning in large lecture classes in STEM disciplines.

Consistent with previous studies, this study confirmed that students considered PRS easy and fun to use, and perceived that it benefited their learning, class engagement, and general classroom learning effectiveness (MacArthur & Jones, 2008). They perceived its use during lectures to be a positive experience even applied as an in-class assessment tool. However, whether PRS use can improve learning and help student performance remains unclear, although some findings of this study reveal this to be the case. These findings could be improved by incorporating an experimental research design to identify genuine learning effectiveness supported by PRS in future evaluations. Limitations of this research including participation numbers, instructional design, or limited data regarding learning style, proficiency, or acceptance of instructional technology were not explored. Further studies should investigate the positive effects of PRS use by addressing these limitations. Additional research is also recommended to examine what specific uses PRS can contribute to certain learning outcomes of large classes in higher education. This study used PRS for only one semester and a longer period is suggested for future research to fully evaluate its effect on teaching and learning. The collection of ConcepTest data over several semesters could also help identify some key concepts challenging students in their first semester of general chemistry.

These research findings indicated the importance of instructional design in PRS use. Most studies evaluating PRS or clicker use do not specify the pedagogical position or value of its application when examining its effects on learners. When used in this study as an in-class assessment tool for both formative and summative purposes, students revealed several disadvantages of PRS use. Their concern related to a lack of clarity and an inability to decipher test questions. Using a narrative interview style for individual reflection may be more appropriate. The findings of this study and results of previous related research reveal that interactive technology such as PRS undoubtedly enable the design of diverse courses.

This is the primary area of interest when studying the effects associated with pedagogical interventions or instructor choices for technology. Considering this perspective, future research should also investigate the effect of variance in instructional design, combined with PRS use.

For faculty members who have not yet taught with PRS and who may be aware of technical problems with earlier models, the results of this study may offer useful insight and encourage them to use PRS. As with other instructional technologies, PRS is simply a tool and does not automatically improve teaching or enhance student learning. Tools can only achieve the desired results with appropriate and effective use (Eilks & Byers, 2010). When introducing PRS to a class, allowing both students and teachers to become incrementally accustomed to its use is advisable (Orzechowski, 1995). In addition to student perceptions, what teachers perceive to be the value and benefits of any particular technology to instruction is also critical (Chen & Chen, 2006), but receives less attention in PRS-related research. Current research on the efficacy of PRS as an alternative assessment approach in promoting student learning still lacks the required control designs as indicated in the earlier discussion. To determine whether technology applications or accompanying pedagogical changes are responsible for the apparent increase in learning requires greater effort to monitor how technology and pedagogy can be merged and integrated into various learning disciplines. The development of effective instructional practice using PRS or any interactive technology in college chemistry learning has significant potential to advance the current understanding of PRS use in education.

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