2006-2551: A COMPARISON AND EVALUATION OF PERSONAL RESPONSE SYSTEMS IN INTRODUCTORY COMPUTER PROGRAMMING

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A comparison and evaluation of personal response systems in introductory computer programming

1. Introduction

Personal response systems (PRS) are being used in classrooms in order for the instructor to obtain real-time feedback on student comprehension of presented concepts. A typical PRS comprises hand-held transmitters, or "clickers," for students to submit answers, receivers that collect the answers, and software that creates the question slides and displays the statistics of the student answers in real time.

In a traditional lecture where the instructor does most of the talking, students are passive, especially in a large lecture hall where students have few opportunities or incentives to ask or answer questions. Even when the instructor asks for responses from students, typically the same small number of students would choose to participate. "The large-lecture syndrome is well known: the professor solemnly expounds his materials, the class passively absorbs it. The professor obtains no feedback and the students scribble notes mechanically…. The major problem to be overcome is the lack of two-way communication between the teacher and the students" [1] A proposed solution to the lack of interactivity in a large lecture is the use of personal responses systems. One of the first hard-wired PRS system was installed for physics education in 1972. In recent years, the development of portable radio frequency PRS systems and associated software has made it feasible to implement a PRS system in classrooms. PRS can be used to provide an "anonymous" way for students to answer questions posed by the instructor, circumventing the discomfort that some students feel about speaking in front of a large class.

Many research studies have looked at the use of PRS, or polling, and have noted positive impacts on learning. However, the comparisons of student learning and engagement have been made *across* semesters for a course and often with polling and other teaching techniques, such as peer instruction, being introduced at the same time. Therefore, the impact of the use of PRS alone has not been determined conclusively. In order to overcome the limitations of the previous studies, this study is designed to compare the use of polling and teaching techniques between two sections of the same course taught by the same instructor with the same assessment instruments in one semester. Interactive lecture techniques and discussion questions are used in both course sections, but the use of PRS is implemented in only one section.

This study explores the following question: Does the use of PRS increase student engagement during class and improve student understanding of course material? The evaluation methodology includes student surveys, student interviews, classroom observations, and a quantitative analysis of the students' final exam scores.

2. Literature Review

The use of PRS or polling systems has been investigated in many studies for student satisfaction and an improvement in learning. A PRS system "engages students during class by providing them with timely feedback, and assisting the instructor in setting the pace for introducing new material." [2] A PRS provides hand-held transmitters that allow students to answer questions in class and the responses are collected electronically using a receiver that is attached to a computer. "Technology has advanced to the point where classroom response systems—or 'clickers'—allow a teacher to sample the thinking of all students, at any time, without students having to risk embarrassing themselves in front of peers."[3]

When a polling system is introduced in a class, many research studies have noted an increase in student satisfaction and an improvement in learning. "Experience shows that the use of clickers transforms the classroom. Student involvement increases…students are suddenly active participants in class, not merely passive listeners to a lecture."[3] Polling systems were originally pioneered in physics and other scientific disciplines, but the use has expanded to a diverse set of disciplines in higher education. "The students reacted very enthusiastically to the system. Attendance jumped to about 95 percent…"[1] Polling systems "have been employed to promote class-wide discussion between learners and the teacher, and also discussion between peers in lectures, in exam revision classes, in seminar groups, and in large group tutorials." The reported benefits of polling include "improved conceptual understanding, more student involvement and better debates, more accurate problem diagnosis."[4]

Polling systems have shown to be effective in engaging students in class, and to help students think about the concepts presented and discussed in class. "Students perceived the clicker exercises to be very helpful in understanding concepts, providing immediate feedback, and helping them feel more comfortable answering when unsure." [5] Many studies have looked at the use of polling systems and have noted improved student satisfaction and engagement during class. "… There is clear research and evaluation evidence supporting the contention that EVS's (polling) improve students learning experience in large group lectures."[6] When a polling system is introduced in a class, research studies have clearly identified that an increase in student satisfaction and engagement occurs.[7,8,9,10,11,12]

The polling technology provides instant feedback to both teachers and students. "Regardless of class size both teacher and students get almost instantaneous feedback about the distribution of student responses…"[13] The feedback feature of a polling system provides a formative assessment of student learning during class that can help to increase the amount of learning, and helps to facilitate student understanding.

In studies conducted over the past ten years, when the polling system was paired with the introduction of interactive or active learning techniques during class there were recognized improvements in student learning.[14, 15] These studies have shown "that such a voting system when used as part of a particular pedagogical method (called 'peer instruction') in a particular disciplinary context …. produces large and statistically significant improvements in standardized test results."[16]

In How People Learn, the importance of formative assessment in learning is explained in the context of educational research. "Formative assessments—ongoing assessments designed to make students' thinking visible to both teachers and students—are essential. And these assessments should provide students with opportunities to revise and improve their thinking."[17] The use of a PRS system provides a mechanism for instructors in large classes to conduct formative assessments during each class and be able to modify the content in response to the assessment results.

As polling technologies have been used in education, the body of research indicates that the use of the technology has the ability to improve student engagement in class, provide feedback about learning and improve student learning, especially when combined with interactive lecture techniques. "Some research has suggested that EVS-enhanced (polling) lectures lead to greater student understanding when compared with more traditional lecturing approaches."[6]

Many research studies have typically looked at the polling experience within a single course. Comparisons of student engagement and learning, with or without polling, have been made between different semesters of a course but have not been made within the same class in a semester. Prior studies have helped to confirm that the use of polling and the accompanying pedagogies can have a positive impact on learning. However, "the absence of a controlled trial and the simultaneous introduction of new teaching techniques … prevent definitive conclusions from being drawn."[7] This study is designed to compare the use of polling and teaching techniques between two groups in the same course which attempts to overcome the limitations of other studies. Interactive lecture techniques and discussion questions will be used in both course sections, but the use of polling will be implemented in only one section of the course.

3. Methodology

This study is conducted in an introductory computer programming course, CS100M, offered to Engineering freshmen. CS100M teaches computer programming using Matlab and Java with examples drawn from engineering and Calculus. Engineering freshmen must choose either CS100M or its equivalent, CS100J, which uses more Java and less mathematics, unless they already have Computer Science Advanced Placement credits. Enrollment in CS100M ranges from 160 to 380 in a semester. The methodologies for technology use, teaching, and data collection are described below.

3.1 PRS Technology and Logistics

In CS100M, students attend two 50-minute lectures and one 50-minute lab weekly. The personal response system (PRS) was used during lecture. The system used was that by Turning Technology and comprised hand-held transmitters, or "clickers," for students to submit their answers, a radio frequency receiver that plugged in to the instructor's computer (USB port), and the software that set up the question slides (a PowerPoint plug-in), displayed a histogram of the responses in real time, and generated reports on students' response data. Unlike the previous generation of PRS that used infrared signals and required receivers wired in a classroom, the PRS used in this study was a radio frequency, portable system. Each student had a designated transmitter for the entire semester so that his or her answers could be tracked.

Students attended one of two lecture sections, 9am or 11am. In our study, only the students in the 9am section were given clickers to answer multiple-choice questions. The 11am section had the same questions but was asked to give their answers by a show of hands or by a voice vote. Other than the use of clickers, the two sections were identical: same content, same instructor, and same presentation including the (clicker) question slides. Students were free to register in either section, but some of them did not attend the section for which they registered. Attendance at the 9am section was recorded through PRS, but for the 11am section attendance was known only for the three days on which in-class quizzes were given. For the purpose of our analysis, we assigned students into two groups: 50 clicker users and 121 non-users. With this binary grouping, a student who used clickers for more than two lectures was classified as a clicker user and all others were non-users, including any students who did not attend lecture.

Figure 1 is an example "clicker question" slide. As soon as the question slide appears during the PowerPoint presentation, the instructor's receiver starts to register the responses—a, b, c, etc.—transmitted from the students' clickers. The countdown timer, shown in the bottom right hand corner of the slide on Figure 1, can be activated at any time by the instructor. After the countdown, the receiver stops accepting answers and can display the student responses as a histogram or a pie chart, as shown in Figure 2. In this study, the resulting histogram was always displayed after a clicker question. More discussion on the questions used will follow below in Section 3.2.

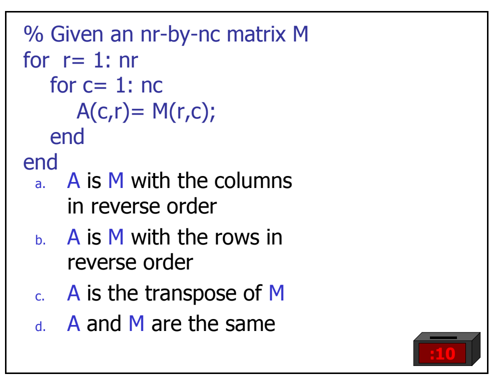

Figure 1. PowerPoint slide of a clicker question as polling begins

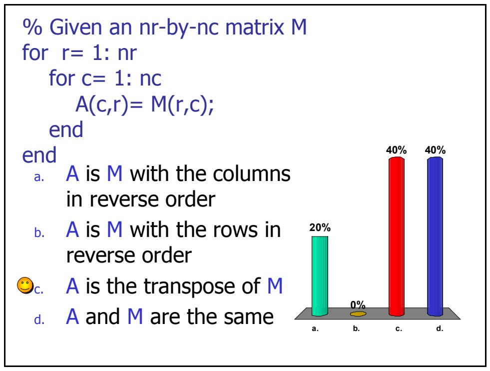

Figure 2. PowerPoint slide of a clicker question after polling when the histogram of student responses is displayed

The PRS was used from week 4 to week 14, the end of the semester. The study began in week 4 of the semester in order to avoid the unstable enrollment and attendance during the university's course change period. The PRS was used without tracking the students' data in weeks 4 and 5 for the students to register their clickers and for both the students and the instructor to become familiar with the system. The student responses were then collected for weeks 6 through 14.

A second instructional technology used during lecture is interactive PowerPoint presentation on a tablet computer, which allows the instructor to easily annotate slides, add new pages of notes, and draw diagrams during the presentation. Interactive tablet presentation is used at both the 9am and 11am sections, while the PRS is used only at 9am.

3.2 Teaching Methodology

In this study, teaching methods that create an interactive classroom environment, with or without PRS, are used. Unlike the traditional lecture where students are passive listeners, an "interactive lecture" involves the active participation of the students in asking questions, answering instructor-posed questions, discussing with peers, and doing exercises on paper. Although this paper focuses on the use of PRS, it is important to note that in every lecture there are interactive activities that do not involve PRS. Using a mix of activities is important not only because the current PRS system is limited to multiple-choice questions, but because the variety helps to keep students interested in lecture. One of the differences between the two sections, is that in the first section the PRS provided a mechanism for conducting a formative assessment and giving immediate feedback to students in the lecture.

The "clicker questions" are used with the PRS in the 9am section and without the PRS in the 11am section. After posing a clicker question, the instructor "collects" the student responses with PRS at 9am or by a show of hands (or a voice vote) at 11am, and then discusses the results immediately. In our study, on average there were three clicker questions in each lecture—at least one and at most 6. The questions were spread out throughout the lecture to fit the material being taught, but often there was one question that reviewed some material from the previous lecture.

The clicker questions, which are strictly multiple-choice, can be grouped into five categories for CS100M, the introductory programming course in this study:

1. **Definition** or **trace**: the question asks for the correct definition of a programming term or the output that would be produced by a code fragment.

2. **Basic application** of definition/principle or simple analysis: the question requires an analysis of some given code to determine its correctness for different scenarios or to identify errors.

3. **Analysis**: the question asks for a code fragment that performs a specific task or follows a particular algorithm.

4. **Conceptual understanding** including design: the question asks the students to compare related programming constructs or choose an algorithm to apply to a certain problem.

5. **Administration**: the question is related to the running of the course, e.g., which topics students would like to be emphasized in an upcoming review session.

Table 1 below gives examples for categories 1 to 4. Categories 1 and 2 correspond to the first three competence levels in Bloom's Taxonomy (knowledge, comprehension, and application), category 3 corresponds to Bloom's "analysis" competence level, and category 4 above corresponds to the competence levels "synthesis" and "evaluation." In the 23 lectures in this study, 70 clicker questions were used in total: 20 definitions/traces, 32 basic applications, 8 analysis questions, 6 conceptual/design questions, and 4 administrative questions. Ten of the 70 questions asked in this study were for in-class, for credit, quizzes.

When developing the clicker questions, the instructor tried to create multiple answers that could arise from common misconceptions or errors. A clicker question was posed typically after a concept was introduced in order to gauge the students' understanding. During lecture, if most students answered correctly, the instructor would simply highlight the important ideas as a review and then move on. However, if a significant number of students had chosen a common incorrect answer, the instructor then would explain why that option was incorrect and ask the students to discuss their ideas with their neighbors before resubmitting an answer. The discussion after such an answer elimination round of polling was always lively, much more so than the quiet discussions that a small number of students had before answering the question the first time.

Table 1. Examples of clicker questions

Category	Example Clicker Question

Definition/Trace	//Quiz Q6: The following statements are in a
	//main method in some class:
	JFrame f1= new JFrame();
	JFrame f2= new JFrame();
	JFrame f3= f2;
	//How many JFrame objects will be created?
	//How many reference variables?
	
	a. 0 object, 2 ref. var.
	b. 2 objects, 2 ref. var.
	c. 2 objects, 3 ref. var.
	d. 3 objects, 2 ref. var.
	e. 3 objects, 3 ref. var.

Basic application	% Given an nr-by-nc matrix M
	for r= 1: nr
	   for c= 1: nc
	      A(c,r)= M(r,c);
	   end
	end
	a. A is M with the columns in reverse order
	b. A is M with the rows in reverse order
	c. A is the transpose of M
	d. A and M are the same

Analysis	In program neighborhood, if you cannot use vectorized code and cannot use function minInMatrix, how many loops will you need? a. 0 b. 2 c. 3 d. 4 e. >4
Conceptual understanding	Which claim is true? a. A for-loop can do anything a while-loop can do b. A while-loop can do anything a for-loop can do c. for- and while-loops can do the same things

3.3 Data Methodology

This study collected data using the following methods: 1.) student surveys, 2.) class observation, 3.) student interviews, 4.) faculty interview, and 5.) data on class performance.

1.) A student survey was administered at the end of the course to collect data to asses the impact of polling on the student experience in one class section and the impact of the interactive lecture techniques in both class sections.

2.) Two class observations were conducted during the semester in both sections to collect data about the level of “active participation” during class sessions. The observations recorded the level of student participation in discussions, and the frequency of student-instructor interaction during class. In addition, the observation recorded the “quality” of the class discussions indicated by student attentiveness and engagement during class.

3.) Students from both class sections were recruited for an interview. Eight student volunteers were recruited from the two course sections and asked to participate in an interview. The interview asked questions about student satisfaction with the use of presentation technologies and interactive class lectures, student satisfaction with the use of in-class questions, student perception of learning during class, and student satisfaction with the use of the polling system (PRS).

4.) After the semester ended, a faculty interview was conducted to review how the faculty perceived the value of the polling system and the impact on student engagement and learning.

5.) Other Data: class performance
At the end of the semester, the faculty reported a summary of final exam scores. The data were reported in aggregate, and the overall mean performance of students between the two sections in the course were compared.

4. Evaluation of the use of PRS in CS100M

The data collected by the five methods listed above were used to answer the question: Does the use of PRS increase student engagement during class and improve student understanding of course material?

4.1 Student Survey

Most students indicated that the use of PRS increased their participation in class. Figure 3 below shows the students’ response to the statement “the use of instructional technologies in this course… increased my participation during class.” “Instructional technologies” refer to the use of PRS for polling and the interactive tablet presentation at 9am. For the 11am section, “instructional technologies” refer to the interactive tablet presentation only.

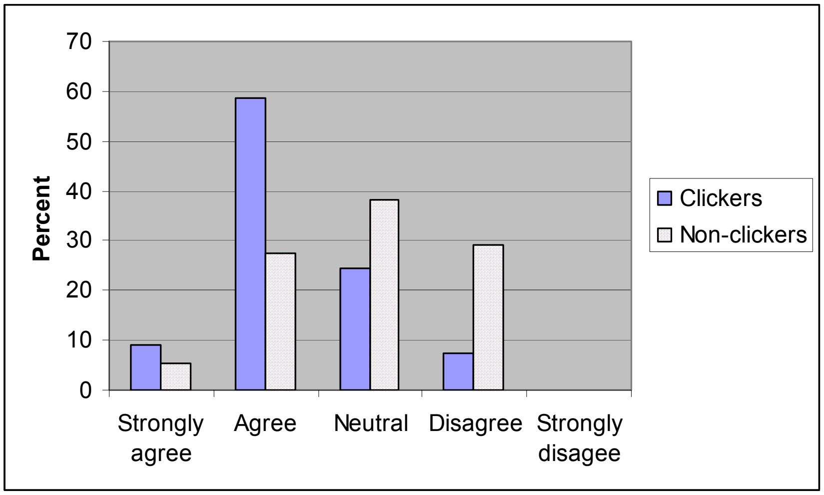

Figure 3. "The use of instructional technologies in this course… increased my participation during class."

The clicker users (9am section) were also asked to evaluate whether the use of PRS helped them learn the concepts in the course. Figures 4 and 5 are histograms of the survey results. Figure 4 showed that 61% of the clicker users felt that the PRS helped them understand the concepts taught in the class. Figure 5 showed that 64% of the clicker users "agreed" or "strongly agreed" that the use of the PRS helped clarify what they knew or didn't know. Forty-four of the 50 clicker users responded to these survey questions.

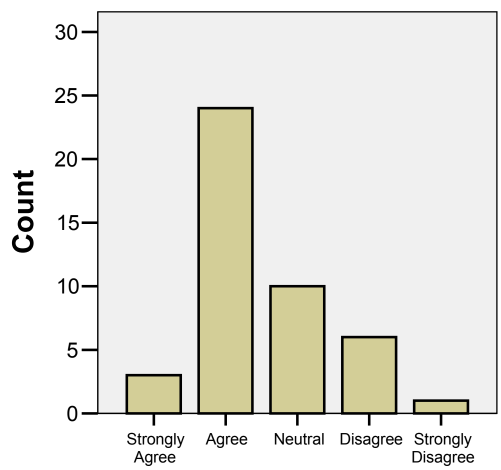

Figure 4. Student responses to the statement "The use of in-class questions with student responses collected by the polling system helped me understand the concepts in this class."

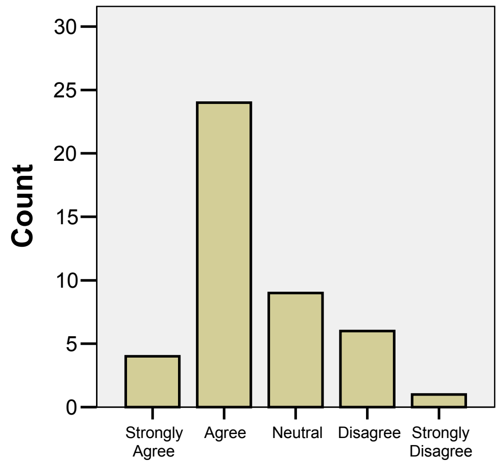

Figure 5. Student responses to the statement "The use of in-class questions with student responses collected by the polling system… clarified what I know or don't know."

Figures 4 and 5 also showed that a small number of students disliked the use of PRS. The student who "strongly disagreed" wrote that the PRS was the "single worst aspect of any college class I have yet taken …"

4.2 Classroom Observation

The classroom observations were conducted to compare the level of student participation in the clicker and non-clicker groups. Observation results show that there was a higher level of student participation in answer to instructor questions in the clicker section than in the non-clicker section. At the 9am section, more than 75% of the students responded to the questions using their clickers. By comparison, participation at the non-clicker 11am section was low:

> *On three occasions students raised their hands in response to the question, the first of which had approximately 15* [of 75] *students raising their hands, the second of which had one student and the third of which had three students raising their hands. On five occasions, students called out answers to questions.*

When the instructor asked questions that were not set up as "clicker questions," the response rate (students raising their hands or calling out answers) was low in both sections. On the two observation days, five to six of the 44 to 50 students in the clicker section volunteered answers to non-clicker questions; six to eight of approximately 75 students in the non-clicker section volunteered answers to the non-clicker questions.

4.3 Student Interview

Students from both the clicker and non-clicker sections were interviewed during the last week of classes. Eight students from the two sections were randomly selected and all of them agreed to be interviewed. The interviews yielded qualitative data on students' satisfaction and their perception on their learning given the use of the PRS. A trend emerged that indicated students participated more in the clicker group.

> "I think that having the clickers actually made me participate more. I realized in the 11:00 lecture (*non-clicker section*), having to just yell out your answer or raise your hand, ... I just did not want to volunteer as much… maybe because of what other people would see that I'm voting for or hear what I'm voting for… or, I don't know what… maybe it was just cool to click... but, I did have more of a tendency to participate with the clicker."

Students indicated that the use of PRS provided a vehicle for students to participate more easily, and anonymously, in a large class. The interviews also revealed that students were satisfied with the lectures that incorporated the *clicker questions with or without* the PRS that collected the data. By creating the questions for use with the PRS, each lecture was structured to allow for review after an individual topic had been taught. This "chunking" of the lecture topics with an "instant review" in the form of a clicker question was noted positively by the students interviewed from both the clicker-user and the non-user groups. A student who did not use a clicker described how the clicker *question* itself helped him stay engaged throughout a lecture:

> "You're forced to kind of look back at it and say 'ok, this is what has happened so far, let me take a minute and actually … review what's going on.' So, I felt it kept me engaged throughout the entire thing. I mean, I'm not a very big morning person … 11:15 is still too early."

As the student comment indicated, the PRS system provided a way for students to gauge their understanding during each class, and the feedback and review process kept students engaged.

4.4 Faculty Interview

From the faculty perspective, one of the goals was to increase class participation. In the interview, the faculty reported that she could observe the increased participation "because I see the [response] meter registers a lot of responses. In class, if where there are about 60 students, usually I have about 40 or 50 answers. Whereas if I had asked that question and they had to raise their hands [to answer], there would be about five or six hands raised."

The faculty also used the PRS to promote student learning through reflection and peer discussion. When many students registered a common wrong answer, the faculty would eliminate the wrong answer and have the students discuss the question with their neighbors:

> "I can see that they've all got it wrong … I would really encourage them to talk to a neighbor to discuss it and then answer again. So, that was new and I actually really liked that; I like that buzz in the room when they realize, 'oh, we were

wrong,' and they talk to their neighbors and try to figure out what the real answer should be."

The faculty's assessment of the impact on student learning as elicited by the type of questions and the changes in the rhythm of the lecture agreed with the students' self-assessment of their level of understanding and engagement in the class. "Changing the kind of things that I do [in a lecture], I feel, is what keeps the students' attention. So I like just having two or three questions spread out throughout the lecture. Because it's multiple choice, the high quality [of the questions] comes in not just in the questions, but in how you set up the answers." Including answers that represented common misconceptions provided opportunities for discussion in class, which could improve students' retention of the material.

The faculty felt that more high level conceptual questions could be developed for the course in the future. However, she recognized some of the constraints on creating and using conceptual questions: the current PRS system required multiple-choice questions, the course was an introductory level programming course, and the need to fit in polling as well as other learning activities within a 50-minute lecture slot.

4.5 Exam Score

The students' final exam scores were analyzed for any difference between the clicker and non-clicker group. The means and standard deviations of the exam scores of the two groups are given in Table 2. While the mean of the clicker group is almost four points higher than that of the non-clicker group, the difference is not statistically significant based on a paired t-test. The power of the test, or the p-value, is 0.15—not low enough to be significant but is not so high as to suggest that there is not a difference. However, any difference cannot be attributed solely to the use of PRS. Students self-select into the 9am section (clicker users) or the 11am section (non-clicker users), so this study is only quasi-experimental—there is not a real control group. In general, as in past semesters, students appear to be more tired at 9am than at 11am and this may have a negative impact on learning for the 9am group. On the other hand, one could argue that some of the students who sign up for a 9am class are more motivated than those who choose an 11am class and that motivation is an important factor in students' performance on exams.

Table 2. Summary statistics for the final exam scores of clicker users and non-users

	Clicker Users	Non-Users
Mean final exam score	80.6	76.9
Standard deviation	12.8	15.5
Number of students	50	121

5. Conclusions and Remarks

This study investigates whether the use of PRS improve student engagement in class and improve student learning. Results from student surveys, student interviews, and class observations indicated that the anonymity provided by the PRS helped to increase the level of student participation. In addition, the regular use of thought questions provided a feedback mechanism and formative assessment in each class that benefited both students and the instructor. Although the mean final exam score of the clicker users are almost four points higher than that of the non-clicker group, the difference is not statistically significant. Furthermore, it is not possible to attribute any difference to the use of the PRS solely, since the study is only quasi-experimental, with students self-selecting join either the 9am (clicker) or the 11am (non-clicker) section. Most clicker users indicated on the survey that they felt that the use of PRS helped them learn the course material.

The results of the student interviews suggest that students benefit from the incorporation of clicker questions into lecture, even when a PRS is *not* used to collect the student answers. This is due to the insertion of clicker questions after a topic has been taught as intermediate "review breaks" throughout the lecture.

Different kinds of questions were used with the PRS, ranging from low level ones such as definitions to high level conceptual questions. One constraint was that current polling systems were restricted to the use of multiple-choice questions. Designing "good" questions was a time-consuming and difficult process. In this study, the instructor always tried to create multiple-choice answers based on common misconceptions. A popular wrong answer presented an opportunity for lively peer discussion that then led students to the correct answer. In this study, most of the questions were in the lower levels (definition, basic application). This was partly because the course itself was an introductory level programming course and that the questions had to fit with other learning activities in a 50-minute lecture. Furthermore, the instructor has had limited experience with using multiple-choice questions and this study was the first time that the instructor had used a PRS. As PRS become more widely used, textbook publishers are beginning to offer polling questions along with their books. The instructor plans to continue the use of PRS and will build up a question bank, focusing on creating more high level questions (analysis, conceptual understanding).

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