Use of Classroom Response Systems in Numerically Intensive Courses

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Abstract

Classroom response systems (CRS) allow faculty to evaluate student knowledge and provide immediate feedback. CRS are frequently recommended in courses where the responses to in-class questions may be conceptual or theoretical in nature. However, recommendations, even from manufacturers, suggest CRS are more difficult to utilize effectively in courses which have largely numerical responses to calculation-based evaluation instruments. Over the course of three years, CRS have been utilized in an electrical engineering technology instrumentation course in a context where the CRS questions are largely quantitative or numerical based from a large set of available equations. This paper will present the methods used to develop the CRS evaluation instruments which have resulted in improved educational outcomes. These methods will include numerical problem decomposition into steps which can utilize CRS, presentation of a numerical problem in a manner conducive to the use of CRS, use of CRS in identifying the appropriate equation for a problem, and generation of numerical problem responses which allow for student errors in the classroom environment. The techniques and results presented will focus largely on example problems from the domain of electrical engineering technology instrumentation, but the techniques may prove useful in any domain which is numerically intensive with a large set of equations and where multiple steps are required for numerical problem completion. Both traditional course assessment data, as well as anecdotal feedback from course evaluation instruments will be presented. This data suggests that, with the proper application and in the correct context, CRS can provide students with an active learning environment and immediate feedback. Both of which anecdotally increase the student’s ability to accurately complete numerical problems on subsequent exam and quiz assessment instruments, as well as increasing student confidence in their own abilities.

1 Introduction

Classroom response systems are a recognized way to improve the participation, engagement and comprehension feedback in the classroom. While they increase the effort required by both the student and the faculty, they also can improve comprehension of the material, and performance on quizzes and exams later in the semester.

CRS are referred to by a range of names (i.e. personal response system, student response system, classroom clickers, voting keypads, classroom performance systems, classroom response systems, audience polling or audience response system) by different manufacturers, advocates, detractors and/or research works. Some of these, such as iClicker [7] are trademarked. In the interest of expediency, we will use the term CRS throughout this paper to refer to any set of devices which can allow students to respond to questions posed by the classroom facilitator, instructor or professor.

For the spring semester of each of the academic years 2007-2010, the author had primary responsibility for the EET3131 Instrumentation curriculum in the School of Technology at Michigan Tech. This course deals with instrumentation of mechanical systems, and as such is highly quantitative in nature. Many of the problems representative of this course require multiple steps to reach a final answer, and selection of equations from a wide set appropriate to a body of knowledge. Examples from the EET3131 instrumentation course will be used in this paper to illustrate the utility of CRS in the context of a numerically intensive course. In the first year, 2007, CRS was not utilized in this curriculum. In the three subsequent years, 2008 through 2010, CRS were utilized with largely positive results. This is not the only course in which the author has utilized CRS, however EET3131 instrumentation contains numerically intensive material, and thus is used as the basis for the results presented herein.
At Michigan Tech, the classroom response system which has been standardized across the university is the iClicker device and base station. This system has been improved through multiple versions of both hardware and software. The current version of the software is 5.4.5 and the current version of the hardware utilizes Radio Frequency (RF) transmission of the data from the response device to the receiver. All of the iClicker equipment is limited to \{A, B, C, D, E\} response set. Much of the discussion of the use of CRS in the context of this paper will be defined by this set of capabilities.

1.1 CRS Outcomes

Classroom response systems are credited with a number of positive outcomes. These can be attributed to multiple sources, but also in most cases are intuitive.

- Take and encourage attendance in lecture
- Maintain student attention & promote engagement
- Create an opportunity for shy students to provide feedback
- Check for and provide assessment of student comprehension to both student and instructor

Each of these are meaningful reasons to utilize CRS, however the pedagogical motivation is the last reason listed. In EET3131 I was most concerned about adequately preparing the students for calculation problems in assessment instruments (quizzes and exams) to be conducted later in the semester.

1.2 CRS Challenges

The use of CRS presents a number of challenges in the classroom environment. First, the addition of the requirement that students purchase not only a textbook, but an electronic device to provide responses. Second, the design of the curriculum must be modified to enable the use of the CRS, which increases workload. And lastly, even with software to assist, the addition of CRS as an evaluation instrument increases the workload required in grade calculations.

1.3 Paper Organization

In the next section we give some background on CRS vendors on how CRS operate. Section 3, discusses related work on the use of CRS in academic settings. Section 4 describes how the CRS are used in the EET3131 Instrumentation course at Michigan Tech, and Section 5 describes the results, both quantitative and qualitative, of the adoption of CRS to the curriculum. Section 6 states conclusions and Section 7 considers future work.

2 Background

The key points to understand before proceeding are, the types of CRS available on the market, and the capabilities.

2.1 CRS Manufacturers

Qwizdom, Turning Point, H-ITT, PRS, IML, Meridia, Fleetwood Reply, Poll Everywhere, eInstruction and iClicker are all manufacturers of CRS; a comparison chart from Poll Everywhere [1] provides a good comparison of the features available from each of these vendors. The systems available from various manufacturers enable a wide range of functionality.

2.2 Response Types

Of these manufacturers, the iClicker [6] allows the most restrictive set of responses. These systems allow only the choice of an \{A, B, C, D, E\} response. This limitation, together with standardization upon this device on the campus of Michigan Tech has driven the development of the curriculum described in this paper. If another type of CRS were available, much of the curriculum design described in this paper would not be required.

Many CRS allow for full numerical response. This is accurate of the products from Qwizdom [10], and most of the other manufacturers. If the CRS is being selected specifically for a numerically intensive course, it would be logical to select a CRS system which enables full numerical responses. This would slow down the conduct of CRS questions, but make the design of the questions simpler by eliminating the need to generate multiple choice responses.

Some CRS allow for free-text response. This is beyond what is necessary for a course focussing on numerically intensive problems. However, free text response may prove useful for feedback from the student to the instructor on material coverage in any type of course.

2.3 CRS Components

The CRS system encompasses at least two, but typically three components. These components are a) the response devices themselves, b) the hardware to receive the responses from the response devices, and c) the software used to collect responses, associate responses with attendees, and facilitate the incorporation of CRS responses into final grade calculations. Each manufacturer provides a unique software and hardware platform. Some allow for integration with course management software (CMS) such as Blackboard, WebCT, ANGEL, Moodle, or others. However standardization between CRS manufacturers is absent in the marketplace.
2.4 CRS Communication

The fundamental communication mechanism used by each of the CRS products may also be unique. Early CRS systems frequently used Infrared (IR), but this type of communication mechanism is rare in modern CRS systems. Only eInstruction and H-ITT still support IR communication in their low cost products. [1] Infrared requires line of sight communication between the response device and the receiver, which can be problematic and limits the number of response devices which a single receiver can service. By far the common communication mechanism for CRS devices in the marketplace is radio frequency (RF). Most vendors utilize a closed standard communication protocol in a public use or amateur portion of the frequency spectrum. [11] CRS vendors maintain this data as proprietary, which is understandable when it is considered that these devices are used in the generation of grades, and it would give an unfair advantage to the student who was able to intercept RF transmission of answers prior to the closing of the response time window.

The most recent innovation in the field of CRS appears to be the addition of the use of smartphones, tablets and laptops integrated with the CRS system software. ResponseWare software from Turning Technology allows the use of an iPhone™ or BlackBerry®, and H-ITT’s SoftClick product allows laptops, cell phones and PDAs. SoftClick works with standard web browsers like Internet Explorer, Firefox, and Safari. PollEverywhere is unique in that it allows responses to classroom posed questions only via the greater network infrastructure, using SMS (Short Message Service) on cellular phones. H-ITT produces CRS software products which enable the use of all three types of response devices IR, RF, or a web based product such as a smartphone or laptop [9] to be integrated in a single classroom environment. This exemplifies the change from a closed single source solution to a more open platform, software based response system.

3 Related Work

The initial use of a CRS in the instrumentation curriculum was motivated by reading the work of Mazur and his colleagues [4]. In the work cited, the overall curriculum design is characterized as peer instruction (PI). Not all elements of peer instruction are utilized in the work described herein, and the reader is encouraged to independently read further into this material. In the instrumentation course, each sequence of CRS questions is used to introduce a course wide dialog, rather than prompt collaboration between a small group of students.

3.1 Educational Outcomes of CRS

Many papers [3] have been written on the use of CRS in the classroom environment. These fall into a number of categories. First, a number of papers focus on the general recommendations on how to best utilize CRS in the classroom [2][12][13]. A second set of papers focus on the educational outcomes representative of the use of CRS in a course. The third category of research focus on how CRS can be utilized in a specific educational field, such as engineering [8], physics [4] or the liberal arts. Certainly, not all CRS related papers fall into one of these three categories, but these capture the majority of the work in this field.

3.2 CRS for Engineering Curriculum

Fewer technical publications have been written focussing upon the numerical curriculum typical of engineering courses. And those papers which have explored this domain [8][12] have largely had the use of CRS which enable at least full numerical response. The material presented in Section 4 is focussed largely upon the design of curricular material for use with a limited response set CRS (i.e. iClicker).

4 Curriculum Design

Instrumentation problems typical to the EET3131 curriculum take many forms. Occasionally these problems may be simple single step calculations or intuitive from the data presented. More commonly these problems require multiple steps to come to a final solution. Examples of the later type of problems include:

- Calculation of Amplifier Gain
- Design Stage Uncertainty
- Expected Sensor Output, in Voltage or ADC Output, given Sensor Input
- Determine Sensor Input value given System reading in ADC input voltage or output reading

These are just a few of the problem types that can be decomposed into multiple CRS questions to illustrate the problem solving techniques applicable to the EET3131 instrumentation curriculum.

4.1 Usage of iClickers

While it is intuitive that iClickers can be used to evaluate course related content, a frequently unforeseen utility of the CRS is to ask impromptu questions in the middle of class to gauge subjective student level of progress or opinions. Each of the following types of opinion questions have been used one or more times in the in the curriculum being described.
Would you like to see additional example problems of this type (A), or has this material been covered to your satisfaction (E)?

Would the best time for the review session be A, B, or C?

Which questions [calculation, multiple choice or fill-in] would you like to see more of on the exam?

Rather than evaluate these questions based upon a correct response, any response is counted for credit. These questions can be presented at any time in the lecture, and improve the interactive characteristic of the lecture. The ability to quickly and accurately gauge the opinions of the class is a benefit of CRS which is not frequently discussed.

4.2 Frequency of Questions

The EET3131 lecture is a conventional one hour (actually 50 minute) time period. In this format, it has proven most effective to conduct a sequence of questions approximately twice per classroom period in the optimal scenario at about the 15 and 35 minute elapsed times. This minimizes the amount of time required to transition from lecture format to iClicker performance, but keeps the students involved.

4.3 Duration of Question Sequences

The duration of the question sequences can be dependant upon the question type, but two to five opportunities for responses has proven workable without becoming cumbersome. This sequence of responses may be from multiple simple problems, typical in the beginning of the semester, or multiple steps in a more complex problem, typical later in the semester. If a single sequence comprises more than five responses the process becomes tedious and more like a quiz than a constructive example. Each of these sequences should be treated as an opportunity to enforce correct problem solving techniques.

4.4 Problem Decomposition

An example of a problem type in instrumentation is the calculation of predicted design stage uncertainty. To perform such a problem, statistics from multiple datasheets, sensor, amplifier, and ADC may be required. Calculation of multiple conversion factors from stage to stage of the system, and relational values (error per bit, or sensor sensitivity, ADC quantization error) must be calculated. Then all of this data must be compiled to generate the final result.

Figure 1 shows a synopsis of the data required for the calculation of a design stage uncertainty, typical of the EET3131 Instrumentation curriculum. Figure 1 will serve as an example of a problem which can be decomposed into a sequence of multiple CRS questions. This is certainly not the only type of question for which this type of decomposition can be performed, but this is the only example which will be examined.

The calculation of design stage uncertainty can be broken into a sequence of problems given in the list below. For the consistency required to enable the pre-calculation of a set of multiple response values, some of these questions, such as the units for calculation, must be predetermined.

1. Determine units for calculation
2. Calculate sensitivity
3. Convert all analog uncertainties to common units
4. Combine all analog uncertainties to an analog uncertainty
5. Calculate quantization error (digital uncertainty)
6. Combine analog and digital uncertainty for overall system uncertainty.

Each of these steps is an opportunity for a CRS question. It has been observed in the classroom that breaking a complex problem into multiple steps can illustrate the problem solving process to the students. Understanding of the sequence of steps required to complete a problem is an important aspect of the course.

4.5 Problem Responses

Each of the problem steps, as given in the example in Section 4.4, presents an opportunity for a CRS question. These questions are constrained by the set of responses available to the CRS hardware. In the case discussed here, we are limited to only five responses.

The most challenging portion of developing the CRS curriculum is creating only five responses, which can be mapped to a set of five options, all of which students may select as being a reasonable response. Typically, the first question in a sequence is a simple calculation required later in the calculation, such as the sensitivity of a sensor. It is suggested that at least one question in the sequence be selection of the appropriate equation from a set of equations.

**Figure 1. Example Design Stage Uncertainty Problem**

<table>
<thead>
<tr>
<th>ADC Specifications</th>
<th>0-10 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>12 bits</td>
</tr>
<tr>
<td>Sensor Specifications</td>
<td></td>
</tr>
<tr>
<td>Input Range</td>
<td>0-50 N</td>
</tr>
<tr>
<td>Output span</td>
<td>0-4 V</td>
</tr>
<tr>
<td>Linearity</td>
<td>+/- 0.6 mV</td>
</tr>
<tr>
<td>Hysteresis</td>
<td>+/- 1 bit</td>
</tr>
<tr>
<td>Sensitivity Error</td>
<td>+/- 0.4 %</td>
</tr>
<tr>
<td>Temperature Drift</td>
<td>+/- 0.1 N / 5°C</td>
</tr>
<tr>
<td>Environmental Factors</td>
<td></td>
</tr>
<tr>
<td>Expected Force</td>
<td>10 N</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>0 to 25°C</td>
</tr>
</tbody>
</table>

**Figure 1** shows a synopsis of the data required for the calculation of a design stage uncertainty, typical of the EET3131 Instrumentation curriculum. Figure 1 will serve as an example of a problem which can be decomposed into a sequence of multiple CRS questions. This is certainly not
related to the topic being discussed. Numerical results should be produced in such a way that all responses are possible of the set of input values are combined in an inappropriate manner. Lastly, the inclusion of, and occasional use of, a “None of the above” option allows for errors on the part of the curriculum designer (and occasional use of) and increased diligence on the part of the students.

5 Results

The CRS questions are intended to serve multiple outcomes. The primary purpose of the incorporation of CRS is to improve the students confidence or comprehension of the material, as well as to improve performance on evaluation instruments to be completed later in the semester. The only way to evaluate the impact of the addition of CRS questions to the curriculums to examine the change in outcomes as CRS are adopted into a course curriculum.

The results from the adoption of CRS can be broken into two categories, these being quantitative results and qualitative results. The quantitative results are the numerical scores which go into calculation of the final grade. In this case, the quiz scores and iClicker scores are the two quantitative which will be presented. The qualitative results are more anecdotal but just as meaningful feedback on the effectiveness of CRS in the course. The qualitative results are documented in end of term course evaluations and reported in first hand feedback.

5.1 Quantitative Results

The first and most direct evaluation of how the use of CRS has improved student comprehension of the material is to examine how students have performed on the written quizzes which most closely match the manner in which the CRS problems are presented. Figure 2 shows a box and

![Figure 2. Quiz Scores by Year](image)

whisker plot representing the quiz scores in years 2007 to 2010. Quizzes are designed to be from zero to ten points. Recall, in 2007 no CRS was used in the presentation of the instrumentation material. In each of the subsequent years, 2008 through 2010, the CRS material was presented prior to the conduct of the periodic quizzes. In each year, the maximum is a 10 indicating that at least one student was able to answer all questions on the quiz correctly. The data suggests that the use of CRS has improved quiz performance by both increasing median quiz performance and reducing the standard deviation. The slight reduction in student performance from 2009 to 2010 may be due to normal variation in students from year to year.

A second quantitative evaluation of the outcomes of the CRS questions is through the student performance of iClicker questions themselves. Because the absolute number of iClicker questions have varied year to year, these results are normalized to 100 to allow comparison between each year. Figure 3 is again a box and whisker plot which shows

![Figure 3. Iclicker Scores by Year](image)

the trend on CRS scores, in this case iClicker scores over the three years 2008 to 2010. As can be seen in each case the maximum value is 100, due to the normalization. The improvement in the median data between year 2008 and 2009 may be due to increased focus on the CRS content, and improved attendance derived from increased focus on CRS. The less significant reduction in median data between 2009 and 2010 is expected to be due to normal variation in student performance. A less well understood outcome is why the standard deviation is smaller in 2009 than either 2008 or 2010. This data does suggest that overall the incorporation of CRS into the curriculum has improved both median student performance and reduced the variation between students.

The three comprehensive exams from the course are also a quantitative assessment of student performance. However, because these exams are only typically 25 to 40% calculation based, and the calculation component was not recorded independently from overall exam score this information is not included in this assessment. The remainder of the exams are typically based upon vocabulary and general knowledge from the field.
5.2 Qualitative Results

During the first offering of the current EET3131 curriculum in 2007, when no CRS questions were presented in lecture, students reported difficulty in completing the numerical problems, despite numerous example problems presented in the text [5] and performed on the chalkboard in the lecture. In the subsequent presentations of the material, students report much more comfort in completing the calculation problems. The most significant difference in the conduct of the course between these two cases is the incorporation of the CRS, otherwise all elements, textbook, lecture, laboratory, and instructor have remained fairly constant.

The standardized course evaluation forms at Michigan Tech allow for free form comments on the back of the form, and these responses are of course widely varied. The three most common CRS related responses provided by students on course evaluations are (paraphrased as): a) add more CRS questions, b) CRS questions improve the understanding of how to perform calculations, and c) I don’t like the use of iClickers in the class. The first two comments suggest that CRS has a positive impact upon understanding course content. However the last comment suggest that there are a minority of students who dislike the use of CRS. It is impossible to know given anonymous evaluations, however it is expected that most of this minority dislike CRS due to the negative impact upon their grade if they elect to skip class. The majority of the students, seem to appreciate the additional information and feedback that CRS provides.

When informally surveyed, approximately four of five students volunteer that they like the use of a CRS in this course. This opinion is not unanimous, as reported above. But the best students appear to appreciate the immediate feedback provided by the CRS to verify their understanding or lack thereof of the material presented prior to quizzes or exams.

6 Conclusion

Both quantitative and qualitative results suggest that the use of CRS improves the outcomes of the course. Performance on evaluation instruments, at least in the short term is improved, and students report improved satisfaction with the material. This is consistent with literature in the field, but is unique in the content of the course and they type of CRS utilized.

While the use of a limited response {A, B, C, D, E} CRS in courses with highly numerical content is more difficult than if a numerical response CRS was available, the use of a such a CRS has still been shown to improve student performance in the instrumentation curriculum. Special attention must be paid to the development of the question sequences, and responses to each of the CRS questions, but the time spent in curriculum development can be amortized across multiple offerings of the course.

7 Future Work

The CRS has proven helpful in the conduct of the EET3131 Instrumentation curriculum at Michigan Tech. It will continue to be used in this course. Future changes will include incremental improvements of the CRS to more closely align format of the CRS content with the evaluation instruments (quizzes and exams) to appear later in the semester.

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