On the Use of Classroom Response Systems as an Integral Part of the Classroom

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Abstract: Classroom response systems are a great technology for enhancing the student classroom experience, and in recent years they have been shown to improve student engagement, aid in knowledge retention, and provide crucial formative feedback for students and educators alike. Unfortunately, it has been suggested that the use of a classroom response system may introduce learning obstructions as well, specifically by confusing participants or distracting students from the material. The authors advocate for a full integration approach of classroom response systems in post-secondary classrooms as a way to preserve the well established benefits while removing the perceived dangers. Such a full integration make use of such systems, not merely as an "accessory" to lectures, but as part of the lecture flow. This full integration allows educators to use classroom response systems throughout the stages of a lecture, but it requires educators to design their lectures utilizing and exploiting the full potential of a classroom response system. The authors' experience with such an approach shows that students highly appreciate it, fully recognize its value, and believe that it enhances their learning experience, all without the perceived threats of distraction or confusion.

1 INTRODUCTION

Classroom response systems (CRS) present an excellent opportunity for instructors to integrate technology into the classroom, and it is widely recognized that these systems can improve student learning and increase student engagement. With the arrival of many new CRS that require only the now ubiquitous smartphone for participation, it is easier than ever to bring CRS into the classroom. Furthermore, with class sizes increasing (due to budget constraints in many educational institutions), finding creative methods to increase student engagement and motivation has become even more important. CRS represent a potential solution - these systems facilitate student participation and provide numerous formative feedback opportunities, students and educators alike. CRS are typically used by posing a question to the entire class and then using the system to record and compile the solutions submitted by the participants. The authors' personal practice also exploits the element of surprise; students need not know when a question will be posed or what the question might entail.

Although the body of literature on CRS presents results that support the use of CRS in the classroom, there are some studies that maintain that the use of CRS in the classroom can present a distraction or otherwise be a barrier to student learning. The authors' thesis is that if CRS are carefully woven into the fabric of a course, these dangers can be eliminated. Such careful integration requires the use of CRS as an integral part of the lecture flow, rather than as supplemental "accessory". The authors believe that lectures present several opportunities into which CRS can be integrated. The systems can be used as a warm-up exercise, a review of or bridge with a previous lecture, an activity for introducing or reinforcing new material, an opportunity for interaction and discussion, etc. It is also worth noting that it is not necessary to include CRS questions at every stage - CRS need not be overused in order to successfully integrate them into the classroom.

The authors have successfully used CRS as an integral part of several different courses, at all levels of an undergraduate program in computer science, on topics ranging from operating system design and computer architecture to discrete mathematics and introductory programming. The CRS questions the authors used were inseparable from the lecture plan and flow, and the authors integrated these questions in a

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wide variety of approaches. The authors have identified ten different categories of questions (albeit not mutually exclusive) that can each be used to design more engaging and interactive lectures, regardless of the classroom size, and with this paper the authors will explore how this deep integration of CRS into the classroom addresses many of the concerns that might prevent other educators from doing the same.

The remainder of this paper is organized as follows. Section 2 discusses related work in the context of the use of CRS. The categories of CRS questions that the authors have identified are discussed in Section 3 and an example CRS is discussed in Section 4. Section 5 examines one of the authors' courses (into which a CRS was integrated) and critically reflects on the student feedback that was received. Section 6 reviews and concludes the paper.

2 RELATED WORK

Many educators first consider the inclusion of CRS activities in their courses as opportunities to improve student engagement, particularly in courses with very large class sizes. This significant application notwithstanding, CRS systems offer another, unique opportunity for formative feedback that can be generated immediately, even in large populations. The feedback provided by CRS can be used by students to discretely self-assess themselves on a specific facet of a larger topic by comparing their own performance against that of the rest of the class. Simultaneously, the instructor can review the performance of all participants and assess how well the corresponding material has been understood by the class, adjusting the pace of the lecture to match the immediate learning needs of the participants.

The effectiveness of CRS in delivering these invaluable opportunities is supported by several extensive studies (Boscardin and Penuel, 2012; Moss and Crowley, 2011; Kay and LeSage, 2009; Bruff, 2009; Moredich and Moore, 2007), and nearly all of the surveyed literature supports the claim that participants are satisfied with the CRS activities themselves. That said, on more than one occasion (Blasco-Arcas et al., 2013; Webb and Carnaghan, 2006), it has been suggested that benefits attributed to CRS by these research studies might simply be the result of improving interactivity in the classroom. Nevertheless, since CRS represent an interactive activity that can be used with a class of virtually any size, it is not unreasonable to state that this application of CRS is almost universally accepted. Furthermore, it has been demonstrated that CRS activity performance is a good predictor of overall performance (Porter et al., 2014), and that, with no additional effort, CRS can be used to identify participants that might be struggling (Liao et al., 2016). Others (Porter and Simon, 2013; Simon et al., 2010) also indicated that they used CRS as one of their best practices for student retention.

The effective use of CRS has been shown to benefit student performance as well. Simon et al. (2013) contrasted the performance of students instructed traditionally against a peer-instructed offering, finding that the peer-instructed subjects (that made extensive use of CRS) outperformed those who were instructed in a more traditional manner. Similarly, Steven Huss-Lederman (2016) reported on a 2-year experiment in which first-year students showed better learning gains as a result of using a CRS. More recently, Collier and Kawash (2017) presented quantitative evidence that CRS questions can be structured and presented in such a way as to improve a participants ability to retain content, by allowing students to revisit content that has already passed from short-term memory.

In contrast with these results, some studies have suggested that the inclusion of CRS activities may not yield any benefits and could in fact actually create a barrier for some students. Robert Vinaja presented (2014) the results of an experiment where the use of a CRS (alongside recorded lectures, videos, and other electronic materials) did not result in a performance improvement. In a broader criticism of in-class discussion in general, Kay and Lesage (2009) discussed how exposure to differing perspectives (that could potentially arise during the discussion following a CRS question) might cause confusion. Similarly, Draper and Brown (2004) suggested that CRS activities might distract students from their actual learning outcomes.

Although those findings are not consistent with the authors' own experiences, CRS do require an investment (with respect to both lecture time and preparation time) and the concern that the activity might be confusing or distracting cannot be summarily dismissed. Nevertheless, the authors believe that the concerns about CRS activities being disruptive or confusing can be addressed by an integrated approach. The authors conjecture that, when a CRS is carefully integrated into the classroom flow (as opposed to being treated as a novel but disjoint activity) these potential barriers will no longer exist.

3 CATEGORIZATION OF CRS QUESTIONS

The exposure to a different perspective a student might receive notwithstanding, for a CRS itself to be considered confusing it would have to represent an activity that was unfamiliar to the class. This concern can be easily addressed by increasing the frequency with which CRS activities appear in the classroom, and since the investment associated with the use of CRS can be weighed against the potential benefits previous noted, the greatest barrier to an education choosing to employ a CRS may be the perception that the system itself might be a distraction. The authors believe this concern can be addressed as well, but in order to properly integrate CRS activities in such a way as they are neither distracting nor disruptive, it must first be recognized that a single CRS activity can take many different forms and address many different needs. By recognizing the role of a question (and answering the question "what do I expect to gain from this activity?") an educator is able to integrate that question into the lecture such that it will not present a distraction. To this end the authors have established a collection of categories for the different classes of questions that can be asked using a CRS. It should be noted that these categories are not necessarily mutually exclusive – an individual question could belong to more than one category.

Ice Breakers: Ice breaker questions are intended to change or influence the classroom social atmosphere in a positive way. These are especially important in the first lecture of a course but can be useful at other times as well. Icebreaker questions can be used to address any stereotypes and misconceptions about the course, the instructor, and the students themselves. In the authors' respective courses, for instance, the authors have used icebreaker questions to address misconceptions about the difficulty of a subject or the importance and relevance of a particular topic.

Being aware and addressing social dynamics in the classroom is crucial. The use of power by educators in learning environments necessitates continued attention because it strongly influences educator-student relationships, students' motivation to learn, and the extent to which learning goals are met. Icebreaker questions can be used to reinforce positive powers (such as reward and expert powers) and avoid the use of negative powers (such as coercive power).

Material Reinforcement / Content Retention: Questions in this category typically include variations of the material being discussed and directly apply the content most recently presented to the students. The interval between the delivery of the CRS question and the presentation of the corresponding material can determine how useful a question can be in improving content retention. The most common practice is to pose CRS questions during or immediately after the presentation of the corresponding material and, in so doing, the CRS question becomes a reinforcing activity (e.g., an additional example), albeit one where student engagement is improved by transitioning students from a passive recipient role into an active participant role. Alternatively, this type of question can be posed after a significant period of time (typically at the beginning of the following lecture). This interval entails that the relevant knowledge has passed out of the short-term memory of the students, and, as a result, the question becomes an opportunity to revisit and review the corresponding content, improving the likelihood that it will be retained.

Feedback: Questions in this category are designed to provide immediate and formative feedback to the students and/or the instructors. Students can use their performance (relative to the other participants in the class) to self-assess their knowledge in the topics being presented, identify gaps that may exist in their current understanding, and even respond immediately to fill those gaps. With CRS systems that allow students to revisit past questions outside of the lectures, student can also review their performance over a particular set of questions, seeking out further resources or assistance as warranted.

The feedback from a CRS activity can also be important to the instructor, since it allows for the immediate assessment of the understanding of the class, providing information on whether and where a specific subject needs reinforcement. If the class (as a whole) under-performs on a particular question, the instructor can respond immediately by providing more examples or by approaching the subject from different angles. Instructor feedback questions can also help in identifying student pitfalls in certain subjects, which can be invaluable in future course development.

Bridging: Often the best way to transition between one subject to another in the classroom is through a problem or discussion and these transitions can be accomplished using CRS questions. While students may not score well on these questions (as they do not reference specific material that has already been presented), they provide an opportunity for students to be challenged by thinking "outside the box" and/or

trying to relate different concepts together. These bridging questions can be designed to motivate the inclusion of the next topic in the course, while, at the same time, relating it to the material most recently presented.

Reflection: After a lecture, The authors often challenge their students to apply their knowledge using higher-level thinking problems. CRS questions can be readily used at the end of a lecture, where the questions are discussed and left with students as homework to answer until the following lecture.

Review: The use of CRS questions in review sessions can make these sessions more engaging and beneficial to students. The authors were able to organize review sessions that required little or no lecturing, and these sessions were highly welcomed by the students. The authors would typically provide students with a practice set of problems in advance and then, during the review session, the students were given a series of quizzes (to be completed in small groups). Each of these quizzes ended in at least one CRS question, testing certain critical aspects of that particular quiz.

Fun Injection: Fun injection is a common technique used to keep a relaxed atmosphere in the classroom, balance the serious tone of the lectures, and give the students the opportunity to stay engaged. CRS questions can be used to occasionally inject fun and these questions need not be orthogonal to the lecture (i.e., there need not be an abrupt transition from a serious topic into a fun injection question). As a clarifying example, a multiple-choice question for which all of the answers are correct can spark an engaging and entertaining discussion, while still focussing on the corresponding material! It should be noted that a question from virtually any other category can be restructured such that it belongs to the fun injection category as well.

Polling: Since most CRS questions can be configured such that the collection of responses can be reviewed anonymously, students can participate in polls to assess their learning, preferred delivery styles, etc. without discomfort. Polling students on the pacing of the lectures or the difficulty of the exams, for instance, can grant students a safe way to voice their concerns without sacrificing the feedback for the instructors.

Attendance: It is worth noting that, in institutions or settings where attendance is a requirement, attendance questions can be easily incorporated into CRS, avoiding the overhead associated with keeping an attendance tally at the beginning of every lecture.

Series: While some may argue that the nature of CRS does not allow working on complex problems and thorough problem-solving techniques, the authors have used CRS to solve complex problems by presenting them as a series of interrelated questions. The step-by-step solution to a complex problem can be converted to a relevant series of CRS questions that will ultimately form a complete solution to the problem. This is, in fact, a very practical and effective approach for teaching students the "divide-and-conquer" problem solving technique.

4 EXAMPLE CRS: "Tophat"

There are a number of different CRS solutions available for instructors seeking to include this activity in their courses. Different solutions offer different features (in terms of data collection, statistics, learning management system integration, etc.) but many of the most recently introduced options allow students to respond with laptops or smartphones (eliminating the need for a separate dedicated "clicker" device). For this paper, the authors have decided to present results from a course into which the *Tophat* classroom response had been integrated, and the authors' experience shows that most students (by far) prefer to interact with this system using their smartphone and a mobile app.

The initial interaction point with Tophat is the Web site `www.tophat.com`. Users (students and instructors) create accounts and, as a part of a user profile, specify a mobile phone number if the user would like to exploit a text messaging interaction method with the system. Instructors can further organize their Tophat account into separate courses. Once a course is created, invitations can be broadcast to populations of students to allow them to join the course. Tophat also has a mechanism to automatically synchronize with class lists on some learning management systems (LMS). Figure 1 shows the main course screen for an example course in Tophat.

Figure 2(a) shows an example CRS question as it appears to students; Figure 2(b) also shows the question the class response statistics screen with the highlighted correct answer.

Each course has three main areas:

- Content: where questions and other content are created

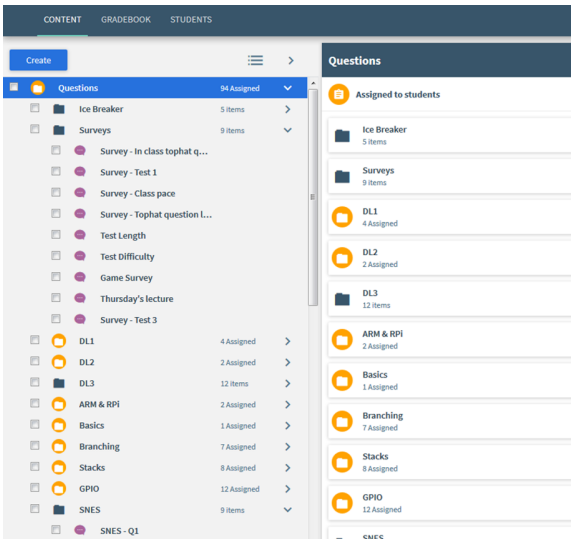

Figure 1: Main course screen in Tophat.

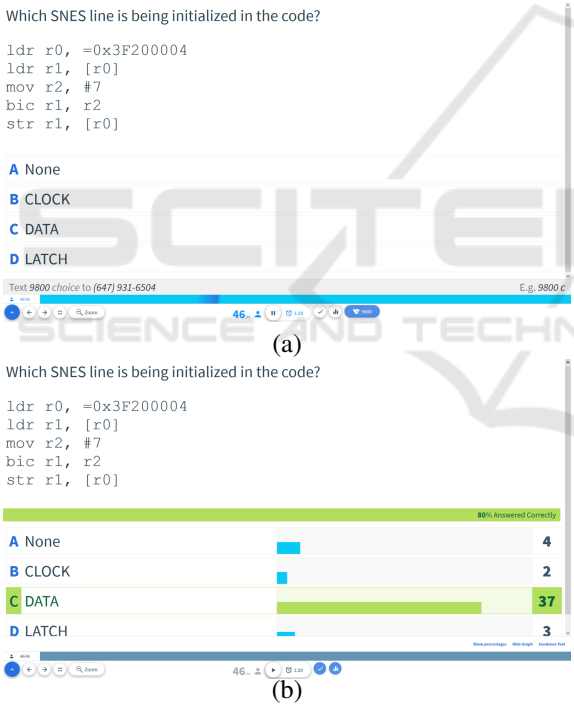

Figure 2: Asking a question in Tophat (a) Question screen (b) Class responses and correct answer.

- Gradebook: a database of student activity regarding answering questions. This activity can be downloaded as a spreadsheet or synchronized with student records on a LMS.
- Students: A list of enrolled students and a mechanism to invite more students

Submissions can be evaluated using a combination of participation and correctness, with the instructor also specifying the relative weight of each question and the relative weights of the participation and correctness components. Instructors can also specify the duration of the question (with students being allowed to submit and re-submit their answers as many times as they wish while the question is active).

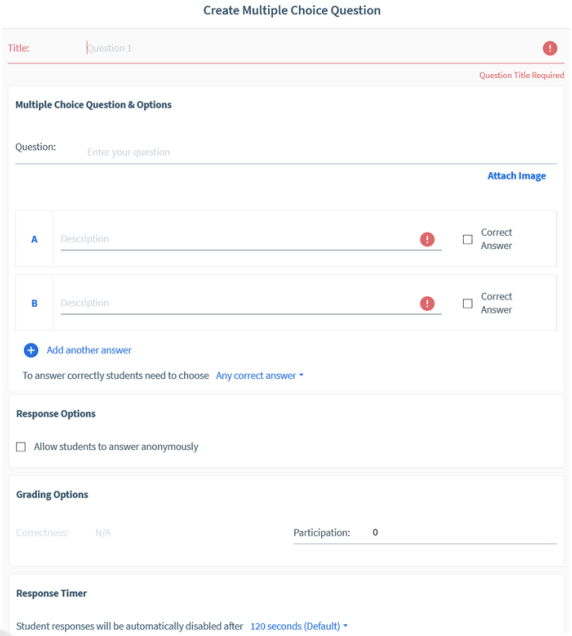

Figure 3: Creating a multiple-choice question in Tophat.

Many modern CRS offer a variety of question types, taking full advantage of the different ways a participant can interact with their smartphone or laptop computer. For the Tophat CRS, there are six question formats that can be created:

Multiple-Choice: Although the practices (and best practices) associated with multiple-choice item creation is a topic that is actively and thoroughly investigated, Tophat allows instructors to pose any type or question (supported by imagery if necessary) with any number of possible answers and no restrictions on how many answers can be considered correct. It is the authors' suspicion that this is the most commonly used question format, both for the simplicity with which they can be constructed and the existing familiarity many students already have with multiple-choice questions.

Word Answer: This is typically used for questions that require a single word or a short phrase response. Although the fact that the student must generate a response (and not just select it from a list of options) may be interpreted as a positive aspect, an unfortunate shortcoming is that student answers that

do not conform to the expected "model solution" might not be considered correct.

Numeric Answer: A numeric answer question requires students to enter a single number as a response. While obviously very useful for testing a students ability to complete accurate calculations, the instructor can specify a tolerance range to make questions for other areas as well. As a clarifying example, a tolerance of 1 and a correct answer of 50 would mean the values 49, 50, and 51 would all be accepted as correct, making this question type suitable for asking students to estimate a particular time-frame, value, or statistic.

Matching: For this format the instructor specifies a list of ordered pairs (e.g., corresponding elements, numerical values, etc.) and Tophat shuffles the elements before presenting. It is then the task of the students to reassemble each ordered pair. Figure 4 shows an example matching question with more responses than premises.

Sorting: Similar to the matching format above, for this format the instructor provides a sorted list of items that is shuffled before presentation. Students are then expected to resort the elements of the list before proceeding. Figure 5 shows an example sorting question.

Click-on-Target: For these questions an image is uploaded and students click on certain parts of the image. The system would then track where each of the students clicked.

It is worth noting that the wide variety of question types is potentially useful for ensuring a learner-centered approach, because students of different learning styles may find some types of questions easier to process (and thus more useful) that others. Were verbal learners, for instance, may be well-served by a body of multiple-choice questions, visual learners might be better served by questions with the matching or click-on-target styles.

Tophat has also other features such as discussion forums and a space for uploading slides and files. These are beyond the scope of this paper.

5 STUDENT FEEDBACK

Both authors of this paper have used CRS as an integral part of most of their courses, and in the authors' experiences, it was only rarely encountered that CRS were distracting, confusing, or unhelpful. Although

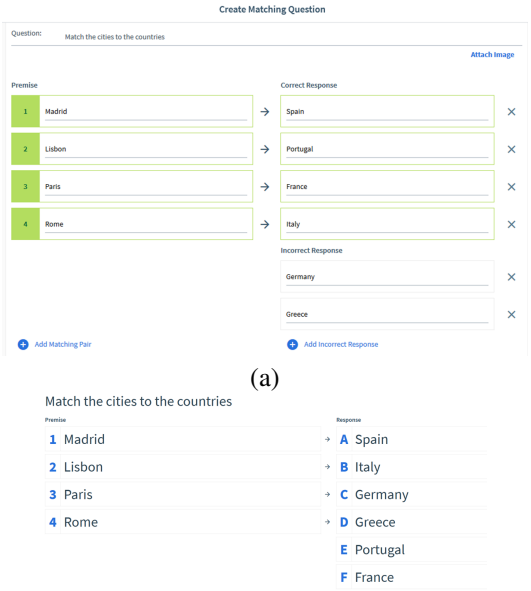

Figure 4: A matching question in Tophat (a) Creating the question (b) Students' view.

Figure 5: A sorting question in Tophat.

it is not unusual for a student to become confused by a particular question (which is obviously something that can occur regardless of how the question was presented) it is virtually always confusion surrounding the material, and not the interface to the CRS. Furthermore, since the authors integrate CRS into their courses very early in the semester, the activity becomes a familiar component of the classroom and is not typically considered a distraction.

In supporting the authors' claims that an integrated approach addresses concerns about confusion and distraction, this section presents data collected from one of the authors' courses into which CRS was fully integrated. This is a second-year, required course in Computer Science dealing with computer architecture and low-level programming. This data was collected over a period of two years from 2015 to 2016 and involved 292 surveyed students - a survey participation

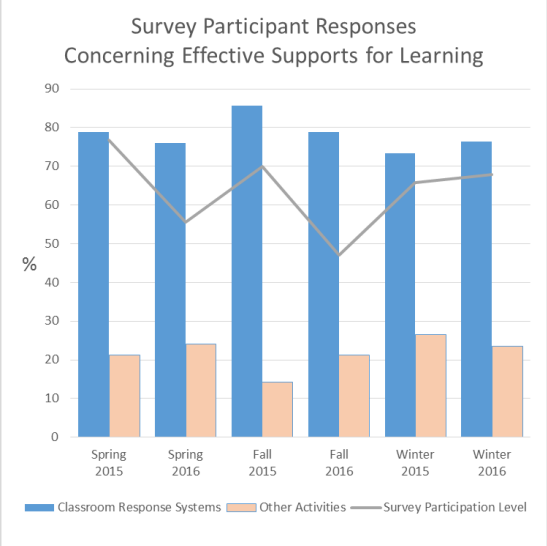

Figure 6: Summary of student feedback.

rate of 64%. During this 2-year period, the course was offered six times: four offerings during regular terms (one offering per term) and two accelerated offerings in during summer terms. The total number of students registered in this course during that period was 459, with class sizes ranging between 43 and 131 students. All offerings of the course during this period were taught by the same instructor and Tophat was integrated into all the lectures in every offerings.

Students voluntarily participate in anonymous surveys required by the university at the end of each term. In these surveys, students were asked about what the instructor did to help their learning and were given the chance to name one aspect that was especially effective in supporting their learning. No options were presented to the students - the question was entirely free-form. 292 valid surveys were received and an overwhelming 77% of the surveyed students mentioned CRS (specifically, Tophat) as the most effective aspect in the course that helped their learning. The remaining 33% mentioned visual aids used by the instructor, group work activities, open-book exams, and the lab assignments. Figure 6 clearly shows that the CRS dominated the survey participant responses concerning especially effective supports for each of the six semesters (which have been arranging according to class size, from lowest to highest).

The authors should note that in Canadian universities, the Fall semester spans September to December, the Winter Semester covers January to April, and the Spring semester consists of May and June (there is also a second short Summer semester in July-August.)

A full table of the values used to create the previous chart is presented in Table 1. In this table, the

Table 1: Student feedback details.

Semester	Course Enrollment	Survey Participants	Participants citing CRS Specifically
Winter 2015	120	79	58 (73.4%)
Spring 2015	43	33	26 (78.8%)
Fall 2015	50	35	30 (86%)
Winter 2016	131	89	68 (76%)
Spring 2016	45	25	19 (76%)
Fall 2016	70	33	26 (79%)
Total	459	292	224 (77%)

rows correspond to the semesters (listed in chronological order) and each row shows the class size, number of students participating in the survey, and the number of survey participants mentioning the CRS as an effective learning support. The fact that the number of students that mentioned CRS specifically never dropped below 73% of the total number of survey participants is a testament to how well the CRS was integrated into this course.

The surveys also included questions where participants could specify what they believe should be changed in order to improve future offerings. Only 2 out of the 292 survey participants complained about the CRS - one student considered it to be a distraction, and the other, while openly recognizing the value of CRS, believed the number of CRS questions presented could be reduced. This means that less than 0.35% of the participants considered the use of a CRS as a distraction, in stark contrast with some of the earlier studies mentioned in Section 2. Furthermore, less than 0.70% of the subjects had anything negative to say about the use of CRS. The authors attribute this overwhelming positive response to the fact that the integrated approach has made the activity familiar and non-disruptive, without sacrificing its effectiveness as an engagement and feedback tool. Digging deeper into the student free-form written comments, many students thought the use of Tophat CRS was engaging. As one student put it:

> *"Tophat kept me motivated to come to class and made the class fun."*

The students also praised the usage of the CRS for its ability to reinforce the material. Some of the student comments included:

> *"Tophat clarified confusing concepts."*

"Tophat cements the knowledge in your head."

"The Tophat questions worked great and help ensure you actually understood what you though you understood."

It is obvious from these comments that well-crafted questions, when properly integrated into the lectures, can help alleviate the illusion of understanding and deal with learning uncertainties by providing an opportunity to practice material and receive immediate, formative feedback. Other participants added:

"Tophat ironed out pretty much all mid-lecture uncertainties."

"The feedback from the Tophat questions allowed you to adjust your focus to areas of need."

Properly integrated questions can help the instructor better explain difficult concepts, by deconstructing the problem into smaller pieces and giving the students the chance to actively work on these problems, rather than turning the students to passive recipients of information. In support of this claim, the authors received the following participant comments:

"Tophat was particularly helpful in understanding tricky concepts."

"Tophat questions were very effective in providing a chance for students to try out new concepts."

"The Tophat questions basically forced you to focus and apply the knowledge."

It is clear that many of these comments echo the well-established benefits associated with the use of CRS. The authors also believe that the results of this two-year investigation provide strong support to the claim that a full integration of CRS into the classroom addresses virtually every concern an instructor might have about adding CRS to their own courses. Although effective CRS integration represents the same kind of investment of time and effort that would be expected of any best practice, the authors believe this investigation has clearly demonstrated that the barriers can be addressed without sacrificing any of the benefits.

6 CONCLUSION

The use of CRS in the classroom has been proven to be beneficial to students since it improves their learning experience in general. The authors advocate for a classroom within which a CRS is fully integrated into the lecture plan. In such a classroom, CRS is not a superfluous accessory to the lecture, but an integral part of it — CRS is used to warm-up, bridge, introduce, reinforce, and review material throughout the entire course. In this paper, the authors have proposed a collection of categories for the different CRS questions that the authors believe clarifies how these activities can be fully integrated. The authors have also discussed a well-known CRS system, called Tophat, exploring how it can be effectively used as more than just a supplementary activity. Finally, the authors have shared feedback, collected from hundreds of students subjected to this integrated CRS approach, over 6 offerings of a single course over the period of 2 years. This feedback overwhelmingly supports the claim that CRS, more than any of the many other activities, was the most effective feature that enhanced student learning. Only a single student from a population of 292 considered CRS to be a distraction for learning, so the authors believe that the call for the full integration of CRS will obliterate the perceived dangers associated with their introduction into the classroom.

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