Using Scanning Apps on Smart Phones to Perform Continuous Formative Assessments of Student Problem-Solving Skills During Instruction in Mathematics and Science Classes

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Abstract - Mathematics and science teachers can now collect samples of student diagrams and multi-step solutions in real-time to make formative assessments of student skills. Students draw their diagrams or perform their solutions on paper, and then scan them with CamScanner® or a similar cell phone app equipped with direct-upload to DropBox® or similar cloud-based file-synchronization system. The instructor creates a shared folder for each class, and subfolders for each question or problem. Students upload scans of their work to the appropriate folder. Within a few moments, the instructor sees everyone's diagrams and problem solutions in a single window and ascertains the level of student understanding so that instruction can be adjusted appropriately to meet real-time needs. In the process, instructors obtain a permanent cloud-based digital record of all student work, allowing them to track student progress over time.

Need for Formative Assessment

Schools and universities have been encouraged to develop a "culture of assessment" to provide evidence on the effectiveness of instructional programs (Weiner, 2009). Although the emphasis on assessment has produced a wealth of literature, legislation, initiatives, reforms, and professional development, the vast majority has focused on assessment ***of*** learning (summative assessment) rather than assessment ***for*** learning (formative assessment). Formative assessment is generally defined as a process used by teachers that provides feedback by which they can adjust ongoing teaching and learning to improve achievement during the process of instruction (Popham, 2008). What makes formative assessment 'formative' is that it is immediately used to make adjustments to instruction to meet the needs of the learners during the construction of understanding (Shepard, 2005).

Limitations of Classroom Response System's & Dedicated Apps

There are numerous Classroom Response Systems (CRS) such as Turning Technologies®, iClicker®, Audience Response Systems® and mobile apps including Socrative®, Poll Everywhere®, TopHat Monocle®, ClickerSchool®, Text the Mob®, Shakespeak®, Naiku Quick Question®, Edmodo®, that can be used to collect information from students for the purpose of formative assessment. Such systems may track individual responses, display results from polls, confirm understanding of key points, and gather data for reporting and analysis. These hand-held dedicated systems allow students to input responses to questions posed by their instructor. The instructor receives immediate statistics on student performance on true-false, multiple-choice and short-answer questions. Studies have shown improved student participation, attendance, and engagement with the use of CRS's (Beatty & Gerace, 2009; Bennett & Cunningham, 2009; Buchanan, 2001; Chevalier, 2013; Gok, 2011; Peat & Franklin, 2002). Such systems not only provide information for teachers, as effective tools in formative assessment, they increase student's accountability for their own learning (Han & Finkelstein, 2013; Akpanudo, Sutherlin, & Sutherlin, 2013; Black & Wiliam, 2009; Kaleta, 2007). Although CRS's have been shown to be a valuable formative assessment tool, current systems do not provide adequate means for free response questions. They have limited input capabilities often allowing a maximum of five response choices and cannot receive audio, video, or graphic responses necessary to assess higher levels of understanding (Price, 2012).

Most CRS's require instructors to create multiple choice and short answer questions prior to instruction. As a result, lessons may tend to be scripted and rigid as teachers adjust their instruction to include pre-written questions. CRS's also require a significant institutional commitment. Such accountabilities include the determination of a common CRS platform on which all departments agree and whether the cost of individual CRS devices will be the student's responsibility or that of the school (Chan, Li, & Tam, 2011). In a recent study identifying ten factors that cause resistance in use of CRS's among secondary school STEM teachers, *timely development of questions* was given as one of the two most significant issues (Beatty, Feldman & Lee, 2011).

The authors consider that a more ideal platform would allow teachers to generate questions "on-the-fly" as they naturally develop in the course of classroom discussion. Each classroom of students is unique, and teachers need formative assessment tools that provide flexibility to ask "spur-of-the-moment" questions of any nature. For example, a teacher may suspect that students are confused about the causes for seasonality. He or she may then ask them to draw a diagram that shows why Earth experiences changing seasons. By analyzing diagrams from the entire class, the teacher may discover a variety of misconceptions and then adjust their instruction to resolve these misconceptions and insure deeper understanding. Unfortunately, such data cannot be collected by dedicated CRS's nor polling/questioning apps. (Herr, N. , Rivas, M., Tippens, M., Vandergon, V., d'Alessio, M., & Nguyen-Graff, D. (2013).

To circumvent the limitations of hand-held CRS's and mobile apps, colleagues at Colorado School of Mines (CSM) developed free web-based software known as *InkSurvey* that enables students to use pen-based mobile technologies to respond to the open-format questions of their instructor with diagrams, equations, graphs and proofs (Kowalski, 2013). The instructor instantly receives student responses and thereby gains real-time insight into student thinking and can immediately reinforce correct understandings and address misconceptions as they develop. *InkSurvey* has been used successfully in college physics and engineering classes with enrollments exceeding 60 students. Researchers determined that when interactive engineering computer simulations were coupled with real-time formative assessment data collected with *InkSurvey*, students achieved large and statistically significant learning gains regardless of their learning styles (Kowalski, 2013).

Although *InkSurvey* is an excellent tool for continuous formative assessment, it requires that students enter their responses directly on devices equipped with touchscreens. There are two issues with this requirement. Firstly, departments will find that the *Ink Survey* is similar to the CRS's in that it also requires institutional commitment in the form of agreement on device platform and professional training. Secondly, many students find it difficult to draw complex diagrams or write detailed solutions on touch screens because they lack the precision that one is accustom to when writing on paper. We suggest that instructors not abandon paper when performing formative assessments. Rather, we suggest that teachers ask students to draw diagrams and perform complex solutions on paper. Students' are then directed to upload their solutions to a cloud-based folder that the instructor can monitor.

Fortunately, it is now possible for students to scan work that they have done on paper and submit it to a cloud-based file system. Students draw their diagrams or perform their solutions on paper, and then scan them with CamScanner® or a similar cell phone app equipped with direct-upload to DropBox® or similar cloud-based file-synchronization system. The instructor creates a shared folder for each class, and subfolders for each question or problem. Students scan their work and upload it to the appropriate folder. This technique affords instructors the opportunity to view the whole of student responses in a variety of useful ways. For example, the scanned work can be arranged as a matrix and projected to the class for review and discussion of the students' levels of understanding. Alternatively, the instructor can view the work privately and select best examples for projection to the class. Following this review and discussion, the instruction can then be adjusted appropriately to meet real-time needs. In the process, instructors obtain a permanent cloud-based digital record of all student work, allowing them to track student progress over time. This provides an additional level of assessment between pre and post-tests (Price, 2012). This session will introduce participants to this innovative and efficient method of collecting real-time artifacts of student problem-solving skills in both face-to-face and online mathematics and science classrooms.

Examples from Mathematics Classrooms

The smart-phone scanning and displaying process has been particularly effective in revealing and addressing the breadth of misconceptions students hold with respect to a variety of mathematical concepts. Traditional formative assessment methods, such as the art of questioning, the exit survey, and the evaluation of class-work and homework also reveal such misunderstandings. However, the traditional methods lack the immediacy in enlightening the teacher of learning errors. Finding and addressing these problems in real-time is a significant feature of the *scan and post* process. It allows the teacher to adjust the lesson to focus on specific areas of need. In addition, *scan and post* allows the involvement of the whole class in the review of their work. Students are naturally engaged as their own posts are reviewed in the context of the posts of their classmates. There appears to be a learning advantage to the collaborative evaluation process between students (Orsmond, Merry & Reiling, 2002; Topping, 1998).

In a recent trigonometry class, the teaching of common sine and cosine values was initially approached by having the students draw 60 degree reference angles in a unit circle. The angles were then to be labeled with the appropriate ordered pairs. Once this was done, the students scanned their drawings to a Dropbox® folder. These were thought to be, in the teacher's mind, rudimentary exercises. The teacher was under the impression that he had presented enough examples. He believed that few students would present a flawed drawing with the possible exception that the labeling of the ordered pairs might be an issue. In fact, the scans revealed that the students labeled the ordered pairs correctly (Fig 1). However, several students' impressions of a 60 degree angle more closely resembled a 45 degree angle (images F1A – F5A in the Fig 1 folder). This was something teacher hadn't expected and was an important revelation. Interpretation of reasonably approximated angles in the trigonometry course is critical in a number of applications. The teacher then applied a new direction of emphasis in the teaching of triangle applications.

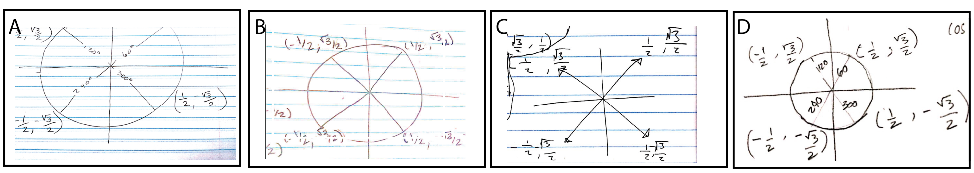

Figure 1. Task: Draw 60 degree reference angles in a unit circle

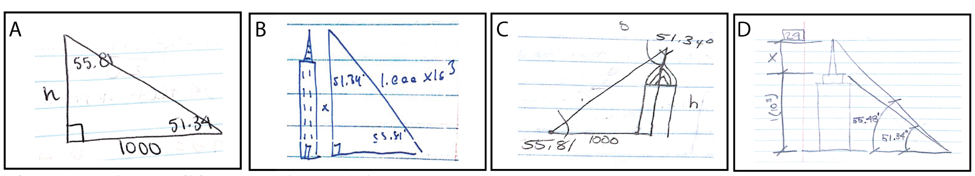

Figure 2. Task: Describing an architectural site

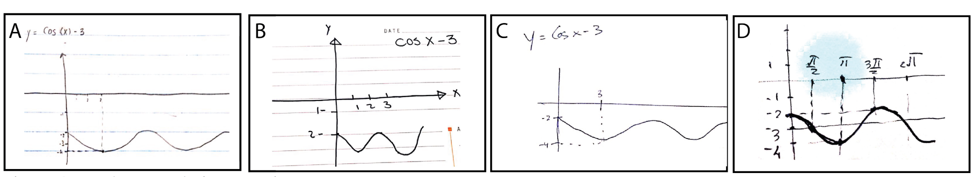

Figure 3. Task: Translating a cosine curve

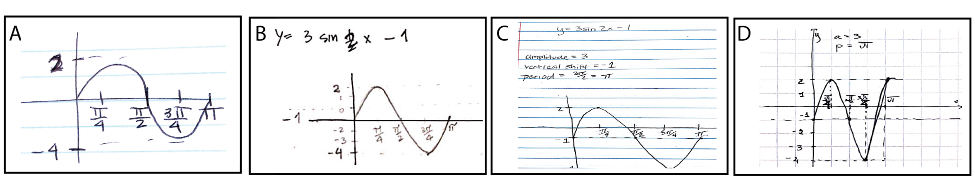

Figure 4: Task: Translating a cosine curve after instructions on labeling axes

In the same class, when students were found to have difficulty with an application problem describing an architectural site, it was useful to have them draw what they thought the problem was describing (Fig 2). There was a profound advantage in displaying the collection of student perceptions and then discussing the posted results with the class. Several students had the same mistake (F2A – F2C). A couple of students had a correct diagram (F2D) and were asked how they interpreted the application. This provided the students additional perspectives from their peers on how to understand the application.

The next exercise asked the students to use their understanding of the sinusoidal-wave graph and translations to render a graphical representation of a trigonometric function (Fig 3). Most students did well at translating a cosine curve exercise but the teacher found that most students had difficulty labeling the horizontal axis (F3A – F3C). The lesson was then adjusted to emphasize methods of labeling graphs. The result was much-improved labeling of the axes in the next class exercise (Fig 4, F4A – F4C).

Examples from Science Classrooms

The *scan and post* technique is an excellent tool for formative assessment in science classrooms. Science teacher candidates were asked to predict what would happen if a 2-liter soda bottle were punctured at three locations while the fluid level was kept constant by "topping off" the bottle through a funnel (Fig 5). The apparatus was placed on a lab table in the front of the room, and teacher candidates were asked to draw a figure illustrating their predictions. The teacher had performed this activity for years, and had generally assumed that the teacher candidates had a good grasp of the factors influencing fluid pressure. The drawings provided much more information than a show of hands could ever show, and highlighted common misconceptions. Approximately one fourth of the teacher candidates drew a diagram similar to Fig 5A, predicting that there would be no difference in fluid pressure as a result of depth in the water column. Another quarter of the class predicted that the water streams would never intersect, as illustrated in Fig 5B. Approximately ten percent predicted that no water would flow out, as illustrated in Fig 5C. Finally, approximately 40% correctly predicted that water would flow farther with increasing depth. The instructor had performed this activity for more than twenty years, each time asking for a show of hands predicting outcomes 5A and 5D. It never crossed his mind that some students would predict options 5B or 5C. Using the *scan and post* technique, the instructor realized students held a wider variety of misconceptions than formerly imagined. At this point, the instructor gave a short lesson on water pressure, after which all of the students redrew their diagrams predicting Fig D. When the activity was performed, the teacher candidates expressed satisfaction that their revised hypotheses were correct.

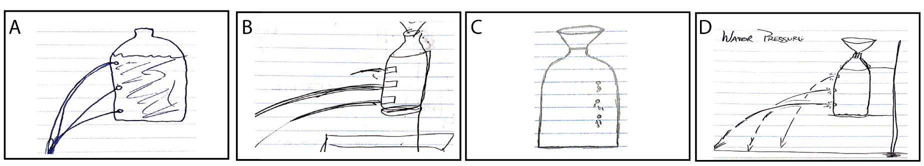

Figure 5: Task: Predicting water flow from a punctured bottle

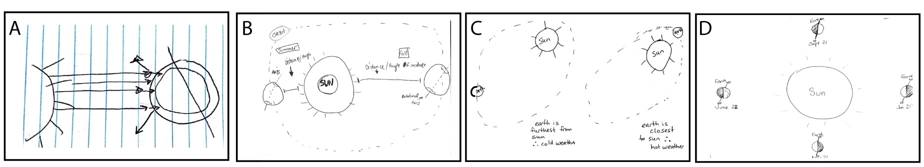

Figure 6: Task: Describing the reason for seasonality on Earth

Fig 6 illustrates sample results when science teacher candidates were asked to draw diagrams that they could use to explain to their secondary school students the reasons for seasonality on Earth. The instructor, an experienced professor of science education, had assumed for many years that the vast majority of science teacher candidates could explain this basic phenomenon. To his surprise, only a quarter of the science teacher candidates produced diagrams that could be used for instruction. The scans revealed a series of inadequacies and misconceptions. Fig 6A shows that the teacher candidate had some understanding that the tilt of the Earth's axis was partially responsible for seasonality, but their diagram was so sketchy and incomplete that it would be useless for instruction. Figs 6B and 6C illustrate a widely held misconception that seasons are due to the elliptical orbit of the Earth. Although the Earth does travel in an elliptical orbit, as do all satellites, its orbit is nearly circular, unlike the highly eccentric orbits shown. Fig 6C illustrates that the teacher candidate had some understanding that the tilt of the Earth's axis was involved, but the diagram shows that he believed the elliptical nature of the Earth's orbit was equally important. Approximately one quarter of the teacher candidates produced correct diagrams such as the one illustrated in Fig 6D. Upon seeing the thumbnails of all explanations, the instructor realized that he would need to address student misconceptions before he could continue with the lesson. More importantly, this activity provided an opportunity to illustrate the importance of diagrams during science instruction, as students critiqued each other's diagrams from the perspective of science learners. The *scan and post technique* provides science teachers with valuable information during instruction so that they can adapt their instruction to the needs of their students

Conclusion

The *scan and post* method helps promote a paradigm shift in STEM education towards collaboration and accountability. Students can no longer hide behind their raised hands. Instead, they must produce diagrams and solutions to illustrate their understanding. These diagrams provide a permanent digital record that can be used by the teacher to gauge growth in student understanding accompanying instruction. Such diagrams provide benchmarks during instruction so that teachers can determine student skills and understanding before summative assessments are given.

The *scan and post* technique encourages metacognition as students see their predictions, drawings, and solutions contrasted with those of their peers. By examining the models of others, they are given the opportunity to reflect on their own thinking. As noted in earlier research, "These activities help students gain an understanding that the learning enterprise requires collaboration, independent verification, and peer review" (Herr et. al,, 2013, p.2). The *scan and post* technique promotes student metacognition and makes possible a degree of continuous formative assessment never before possible. Teachers are provided real-time snapshots of student understanding that can be used to reform their instruction to meet real, rather than perceived, student needs.

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