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Using Mixed Mobile Computing Devices for Real-Time Formative Assessment

Prof. Frank V Kowalski, Colorado School of Mines

Prof. Frank Kowalski has been teaching physics at Colorado School of Mines since 1980.

Susan E. Kowalski, Colorado School of Mines

Susan Kowalski is project coordinator at Colorado School of Mines.

Dr. Tracy Q Gardner, Colorado School of Mines

Using Mixed Mobile Computing Devices for Real-Time Formative Assessment

Abstract

Increasingly affordable mobile computing devices can be used effectively to facilitate real-time formative assessment. Students equipped with pen-enabled Android devices, iPads, iPhones and/or tablet PCs can use digital ink to reveal their thinking as they construct new understandings of concepts.

InkSurvey is free, web-based software (ticc.mines.edu) designed specifically for collecting student responses for real-time formative assessment. During the learning process, the instructor poses open format, embedded questions to probe student understanding. Students respond with words, drawings, graphs, or equations "inked" on either their own devices or those provided by the institution. The construction of these responses actively engages the students with the subject material and increases student metacognition. The instructor, instantaneously receiving this feedback, has a real-time glimpse into the minds of the students and can address lingering questions, repair misconceptions, and make better use of class time.

We describe significant recent improvements to *InkSurvey* that have made it more fully functional on a greater variety of devices and more user-friendly for both instructors and students. Specific classroom examples and results are presented to illustrate student metacognition, how student thinking changes over time, and changes in instructor responses and approaches to learning. Potential use of this technology-based teaching tool outside of the traditional classroom, for example in a distance-learning environment or for Just-in-Time Teaching (JiTT), is also discussed.

To provide additional context, a brief overview summarizes some of the varied applications and settings in engineering education in which the use of *InkSurvey* has been previously explored: increasing learning gains, improving problem-solving skills, and enhancing learning gains achieved when coupled with computer simulations. Real-time formative assessment collected with *InkSurvey* is blind to gender, personality biases, and other stereotypes, making it a particularly effective tool in group and cooperative learning environments. This also opens the door to additional applications in non-academic settings as well.

Introduction

When the National Research Council tackled the task of compiling what we know about how people learn, their report in 2000 distilled findings arising from the recent explosion of multi-disciplinary scientific studies of the mind, the brain, the process of thinking and learning, and the associated neural processes.[1] They concluded that key research findings from the emerging science of learning point to four attributes that need to be cultivated when designing environments for optimal learning; one of these is frequent formative assessments (p.24). Over a decade has passed. Recently, another National Research Council committee of experts considered best practices for developing deeper learning and 21st century skills and released their recommendations, which again included the use of formative assessment.[2]

Real-time Formative Assessment

In 1998, Black and Wiliam[3] published an influential meta-analysis of 250 articles and chapters about formative assessment; their broad working definition remains widely used today. With strong theoretical underpinnings, formative assessment includes all activities performed by instructors and students to provide information about student understanding during the learning process; this evidence is then used to give students feedback about their understanding and adapt subsequent teaching and learning strategies to meet student needs. As the label has become more widely (and sometimes inappropriately) used, others have issued reminders that formative assessment is not about the instrument, but rather the dynamic process. [e.g., 4,5]

It has been particularly challenging to incorporate the process of formative assessment in the higher education setting.[6] Ideally, formative assessment should be seamlessly embedded in instruction, to capture students' thinking while they are constructing new understanding.[7] Also, in order to be effective in influencing subsequent instruction and learning (that is, in order to be "formative"), the instructor needs to receive and respond to student input in a timely manner.[3] Without technology, all of this tended to be a cumbersome and time-consuming process. Personal response devices ("clickers") and other polling devices, which have become widespread in the last decade, allow instructors to collect multiple choice and short numerical student responses quickly and painlessly; these can provide effective real-time input for formative assessment. Their limitations, though, cannot be ignored: difficulty of essential divergent assessment (assessing students' ability to succeed in more open-ended tasks involving higher level thinking skills), [6] distortion of student responses by providing a menu of possibilities, raising the noise-to-signal ratio due to guessing, and inability to simulate most job-like environments.[8]

There are a variety of ways to overcome these shortcomings. One possibility is to have students equipped with pen-enabled mobile devices (Tablet PCs, Android devices, iPads, iPhones, etc.) respond to open-format questions posed by the instructor, who receives the student responses instantaneously. Although until recently this was cost-prohibitive in most educational settings, the increasing availability of inexpensive mobile devices has now made this more practical. There are other software products available that could facilitate this (*e.g.*, Classroom Presenter), but here only *InkSurvey* is discussed. After a short description of *InkSurvey*, the student perspective, the teacher perspective (including challenges to be met), and various applications are discussed.

InkSurvey

InkSurvey is web-based software designed specifically to facilitate the collection of student responses for real-time formative assessment;[8] it is available for free at ticc.mines.edu. During the learning process, the instructor can use embedded open-format questions to probe student understanding. Students access *InkSurvey* to respond with words, drawings, graphs, or equations "inked" on either their own devices or those provided by the institution. The instructor, instantaneously receiving this feedback, has a real-time glimpse into the minds of the students. This insight into student thinking and understanding then allows the instructor to address lingering questions, repair misconceptions before they are deeply rooted, and make better use of class time.

Since *InkSurvey* is web-based, it is not essential that all student devices being used in a classroom be alike. Also, it means there is nothing to download onto the devices locally. This is significant since many students walk into class already equipped with personal mobile devices that can be used for constructing real-time responses to open-format questions posed by the instructor to probe their understanding. In addition to relieving the institution of the expense of providing and maintaining devices for students, this is very attractive since it 1) eliminates class time needed for distribution and collection of devices, and 2) allows students to more seamlessly integrate their preparation of responses with other class activities, such as note-taking or doing calculations, on their personal devices.

Currently, *InkSurvey* is fully functional on the following pen-enabled mobile devices: Tablet PCs (using the Firefox browser), iPads, iPhones, and Android (4.0 or better) devices. Recent improvements ensure that the display expands to the full screen on all of these devices, making graphical input easier.

Since the instructor controls when and how many questions are launched, it is possible to use *InkSurvey* for differentiated learning. For example, the instructor can initially pose a question about a concept that has just been covered in class. When submitted student responses indicate that at least some students have mastered this, the instructor can then activate another question, perhaps for enrichment or involving another application of the same concept, to continue to engage the faster students while other students continue to work on the original question. In this way, an instructor can better meet the needs of different students, even in a large-class setting.

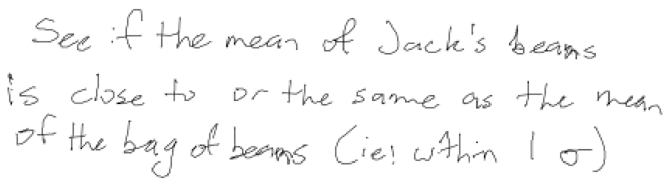
Student Engagement

Constructing a response with digital ink clearly requires a student to interact with the concepts being presented in a much more active way than does simply sitting in a lecture. Designing classroom experiences around such active learning strategies has widely accepted theoretical underpinnings. In a survey of 19 faculty members using Tablet PCs around the world to facilitate real-time formative assessment, respondents strongly agreed that this teaching model engages their students in a manner unmatched by their previous classroom teaching experiences.[9] It is worth noting, however, that this active role can create some stress for students if they see real-time formative assessment as requiring them to "perform" immediately when learning about a new concept. Just as when using clickers for real-time formative assessment,[10] students will be more welcoming of both constructing responses and receiving feedback if they understand this process is based on the instructor's interest in refining their understanding and repairing misconceptions.

One advantage of the process of formative assessment is the increase in student metacognition[1]—that is, students come to realize what they don't know, what they do know, and how they know it. A corollary of this is that once students realize they don't know something, they are more receptive to instruction and are "primed" to learn. This motivation is difficult to measure, but appears repeatedly in student attitude surveys we have collected. These two examples of student comments reflect some of these ideas:

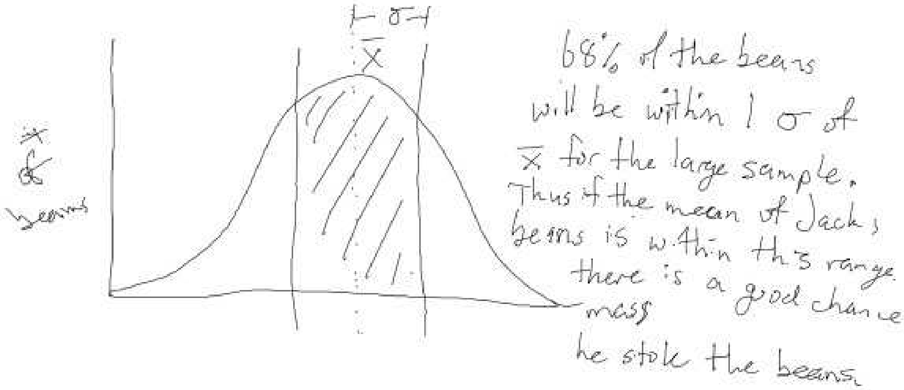
- "It's good to be able to formulate an answer right away to see if you understand it. Without it, when a professor is teaching something new, you think you know how to do it until you try to work on it later and realize there was an aspect you needed clarification on. By working on a problem right away in *InkSurvey*, you find out immediately which points are clear and which are not. The professor also sees right away if I need more help or have things wrong. It sometimes… makes me realize I know something better than I thought I did or I already knew how to do it and that it's not as scary as it may seem when it's presented." Submitted by an engineering physics student, Fall 2012
- "I find that *InkSurvey* helps me realize if I do not understand a concept, but the lecture afterwards helps me actually understand the material better…." Submitted by a chemical engineering student, Fall 2012

By comparing responses from a single student to a series of open-format questions posed with *InkSurvey*, one can see how student thinking changes over time. The example comes from application of the standard deviation of the mean, all done in one class period in an engineering physics course. The students were given the problem that Jack was caught with 100 beans in his pocket in a small town. There is only one store that sells beans and we know the mass distribution of those beans. Questions A and B deal with this application of the distribution of mean values.
Question A: How would you know if Jack stole those beans from the town store? The particular student we are following submitted this response:



In this response, the student does not utilize the mass distribution of the means for groups of 100 beans, but rather uses the distribution of individual bean masses. About half of the other student responses shared this misconception. Therefore, feedback was given in the form of a short lecture on the distribution of mean values.

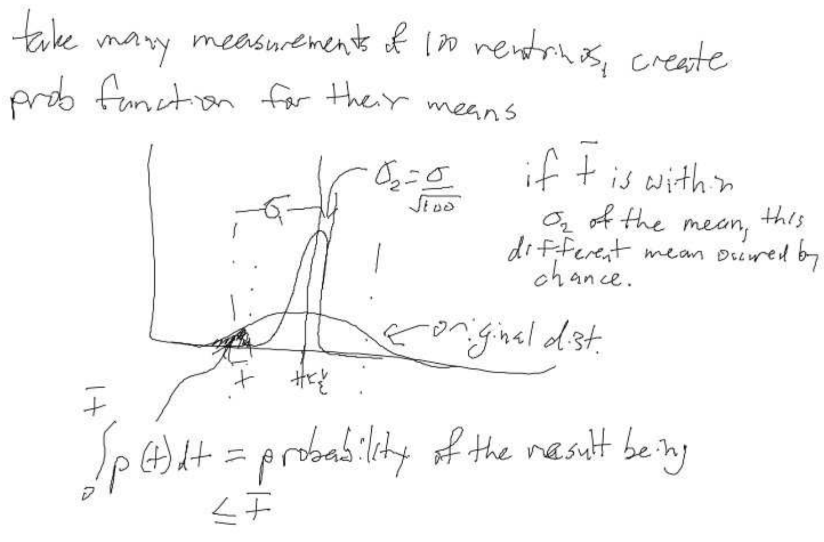
Next, the students were presented with Question B: Sketch and label a graph which allows a quantitative measure of the chance that the beans were stolen. Following the thoughts of the same student, this is the response submitted:



Here the student gives details of how the calculation is to be done, but still does not understand the advantage in using the distribution of mean values for 100 beans. Instead, he/she continues thinking only about the distribution for individual beans. Since this misunderstanding persisted in about one third of the responses, it was again addressed in a short lecture on the solution to Question B.

Finally, the students were given the problem of determining the arrival time of a pulse of 100 neutrinos at some distance L from the source; this is related to the recent neutrino experiment that reported motion faster than the speed of light and was therefore of particular interest to the students. Question C deals with this application of the distribution of mean values: Sketch a graph that indicates how to calculate the 100-measurement average of neutrino arrival times occurring just by chance.

The student we are following submitted this response:



This response indicates that the student now understands that the distribution of mean values leads to less uncertainty in determining the arrival time as opposed to using the distribution of individual arrival times. This response also indicates an understanding of how to calculate the probability that the value obtained could occur just by chance, and how to transfer the concept between different contexts. Considering each of these responses as a snapshot of student thinking at a particular moment in the class, one can see the progressive construction of new, successful understanding of the underlying concept.

There has been a lively debate in the literature about the validity of attributing specific learning gains to the formative assessment process in particular. [4,11] The crux of the concern is in determining how effectively the information provided by the student is used by the instructor to inform subsequent instruction that closes gaps between the current and desired levels of student understanding. Even though we recognize the necessity of greater attention to the nature of the instructor response to correlate student learning gains and the formative assessment process, initial studies of the effectiveness of *InkSurvey* have not addressed this rather elusive metric directly. However, in the sequence of student responses above, it seems there is at least a strong possibility that the changes over time in the thinking of this student are in response to the process of real-time formative assessment, and that the timely guiding feedback provided by the instructor would only be possible when the instructor has a real-time glimpse into the minds of the students, to see their thinking at that point in time.

Instructor Engagement

To date, the largest class in which we have used *InkSurvey* to collect student responses for real-time formative assessment had 80 students. An instructor might be apprehensive (or downright frightened) about receiving such a large number of student responses at once. Since the questions are open-format, one needs to look over the responses individually, rather than aggregate data of percentages correct delivered by the software. However, those concerns are allayed by two important considerations. First, student responses will not all arrive simultaneously, since not all students work at the same rate. This provides an opportunity for the instructor to view the incoming responses and consider his/her best response. (Additionally, it also provides an opportunity to coach students with gentle reminders of important things the early responders may have overlooked or failed to incorporate in their responses.) Secondly, one must consider the graphical nature of the responses. A picture (or graph or diagram) can indeed be worth a thousand words in response to a question probing student understanding, and a quick glance at these student responses can reveal much about student understanding and misunderstanding. Multi-sentence prose responses are more difficult to assess quickly and present a greater challenge in large classes.

Whatever the format of the responses, however, the instructor response is a critical component of the formative assessment process. In an influential work on formative assessment and the design of instructional systems in 1989, Sadler[12] pointed out the "puzzling observation that even when teachers provide students with valid and reliable judgments about the quality of their work, improvement does not necessarily follow. Students often show little or no growth or development despite regular, accurate feedback." Aiming to improve the chances of student progress, he highlights the importance of students developing the capacity to monitor the quality of their own work, based on an appreciation of specific hallmarks of high quality work. This can be facilitated with *InkSurvey*, as exemplary responses from students can be displayed to the entire class and discussions can go far deeper than "correct" and "incorrect" and students can gain practice in evaluating their own responses in comparison.

Skilled instructors translate their interpretations of the formative assessment results into instructional actions that match the learning needs of the students,[13] blurring the line between scaffolding and formative assessment to move learning forward.[14] The real-time nature of *InkSurvey*, although very powerful, places a special pressure on the instructor. No longer can the instructor come to class with a clear, well-defined script for the day's lecture. Instead, the instructor finds himself metaphorically "negotiating a swiftly flowing river" in class.[15] This requires agile teaching and the flexibility to deal with the unexpected, which is perhaps outside some instructors' comfort zones, particularly for novices or those not confident of the subject matter.[3] Additionally, it encourages the instructor to give thought beforehand to possible student misconceptions and alternative routes for constructing correct understandings, so that on-the-fly adjustments may be more effective. Also, the insights gained by the formative assessment can be useful for planning subsequent class sessions. Whether immediate or delayed, though, the responsive action by the instructor must accompany the intent of gathering the student responses to inform instruction.

Elsewhere, there are indications that the greatest challenge for instructors is in knowing what to *do* once the student responses have been received. If an instructor conveys the attitude of looking solely for a particular response, this can actually inhibit future learning of the student.[3] Furthermore, a study involving 118 math instructors teaching three common mathematical principles found that teachers are better at identifying principles and drawing inferences about students' understanding than they are at deciding the next instructional steps.[16] In another recent study[17] of how middle school mathematics teachers responded to formative assessment received from their students revealed a broad range of responses, from simple binary statements ("I learn whether they get it or not") to highly nuanced observations about students' understanding of details and processes. The most highly nuanced insights into student understanding described in the study involved explorations of students' thinking, such as examining where a solution method broke down and why. Although these professionally-trained teachers were not necessarily receiving the student responses real-time and needing to change instructional strategies on the spot, the researchers noted that, "Unfortunately, it was rare to encounter instances in which practices embodied all the ideal characteristics of formative assessment (i.e., assessment with instructional improvement as its purpose), which occurred frequently and were related to content currently being taught, as well as were integrated thoughtfully with instruction" (p. 27). On a more upbeat note, the study concludes that formative assessment has great potential to improve student learning and is still a relatively new mindset and practice for most instructors.

The richness of the feedback instructors can get from posing open-format questions with *InkSurvey* can inspire in-class exercises that lead to significant increases in student understanding of concepts. In an actual classroom example in a Fluid Mechanics course, students were asked the following series of questions using *InkSurvey*:

1) What is a fluid?
2) What is viscosity?
3) a) Would you expect liquid viscosity to increase or decrease with increasing temperature? Explain.

b) Would you expect gas phase viscosity to increase or decrease with increasing temperature? Explain.

Many student responses to the first question were good. Some answers were along the lines of "Fluids will flow when a shear force is applied to them" and "A fluid is a liquid or something that flows as a liquid does" and "A fluid is a flowing substance that has a measurable viscosity." However, common misconceptions were also identified in answers to the first question, including that: 1) a fluid is specifically a liquid, as if the two were synonymous, 2) a fluid is incompressible by definition, and 3) a fluid fills its container.

Answers to the second question indicated that students had the basic understanding that viscosity related to how easily fluid flows, but did not really understand how. Some had the relationship between viscosity and ease of flow exactly backwards. Others could not distinguish between density and viscosity. Some common answers about viscosity were along the lines of:

"The friction between the molecules within the fluid."

"The ease with which a liquid flows."

"The thickness or density of the fluid."

"Viscosity is the resistance to flow."

"Viscosity is the property of a fluid that describes the cohesiveness (stickiness?)."

These answers illustrate that it can still be difficult to really get at the details of a student's understanding even with answers in their own words. For example, it could be that a student answering that viscosity is a measure of ease of flow truly understands that it is a measure of resistance to flow instead but chose their wording poorly, or maybe they really think that fluids with higher viscosities will flow more easily. Here a clicker question might have had "ease of flow" and "resistance to flow" both as options, in which case the student would realize there is a difference and have to choose one (that is, assuming they realized one of those was a better answer than other choices such as "density" or "thickness"). Or, if the possible answers included only "resistance to flow" along with other more distinct and incorrect choices, a student thinking it was "ease of flow" would be pigeon-holed into answering something else, and the true misunderstanding would be more difficult, or even impossible, to glean.

In this particular case, to get at the distinction between ease of and resistance to flow, the third question was asked. Having "Explain." at the end of an open question like this requires the students to think things through carefully enough to justify an answer and also allows for deeper understanding by the instructor of the students' thinking. Answers to the third question showed more confusion and misunderstanding, and *because of the students' opportunity to explain in their own words*, these answers indicated to the instructor what specifically was misunderstood and suggested how to help the students better understand the concepts. For example, one student said, "a) I would expect that as temperature increase viscosity increase (sic.). (think of warming up honey) and b) I would expect gas phase viscosity to increase with increasing temperature." From this response, especially given the example of warming up honey, it is clear that the student thinks of viscosity as a measure of ease of flow as opposed to resistance to flow. Furthermore, notice that the student had the correct answer (that gas phase viscosity tends to increase with increasing temperature) but apparently *for the wrong reason* – i.e., that a gas and a liquid would behave similarly, as most students stated in answering this question. The student had two misunderstandings that canceled out and would have led to a correct answer on a clicker question about whether gas phase viscosity tends to increase or decrease with temperature. Several responses to this question were similar to the following one: "I would expect liquid viscosity to decrease with increasing temperature because as molecules in the liquid move faster due to increasing temperature, they can slide past each other easier. The same would be expected for gases." Students providing such responses seem to properly understand the concept of what viscosity is, but they don't understand how it is affected by the orders of magnitude difference in density between phases.

Reading these responses and learning specifically what misunderstandings there were and what was leading to them, the instructor came up with a demonstration on-the-fly to correctly illustrate the concepts. She asked for volunteers from the class to be molecules. She had them first be a liquid. They grouped close together and tried to move randomly around. She "applied a shear force" by gently pushing one side of the group. The students found they were running into each other a lot and had a relatively difficult time "flowing." She asked the class as a whole if the fluid group's viscosity was high or low in this situation. Most of the class had correctly understood that viscosity measured resistance to flow, so with group discussion they came to the consensus that the viscosity was high. Next, the instructor told the "molecules" they were now hotter, and they moved around faster and found it easier to "flow" when pushed. She asked if the viscosity had gone up or down. Now that the class understood what viscosity is, there was complete agreement that it had gone down. Then the instructor told them to be a gas, and they moved much further apart, again still moving around randomly as they had finite temperature. Here she pointed out that they had just greatly decreased their density, and asked the class to discuss the difference between density and viscosity. She again applied a shear force, and they "flowed" with ease. Finally, the instructor told the "molecules" they were even hotter, so they moved around even faster. They found, to their great surprise, that they actually ran into each other more, and therefore found it more difficult to "flow" (*i.e.*, their viscosity had increased). From this exercise, the students learned the difference between density and viscosity, that both liquids and gases are fluids, that viscosity is a measure of resistance to flow, what a shear stress is, and how liquid and gas viscosities vary with temperature (and more importantly, *why!*). It is difficult to imagine what series of clicker questions would have led to the same level of understanding on the instructor's part, of the students' *mis*understandings, to suggest such an exercise.

In order to strengthen the partnership between instructors and students in the learning process, a new feature has been recently added to *InkSurvey* to further engage the teacher as student responses are received. To use the sorting feature, the instructor first uses the "Admin" page of *InkSurvey* to view the student responses for a particular question (even if none have yet been received). By selecting "Manage Bins for Questions," the instructor can then establish and label bins tailored for that question. As each bin is established, there is also a check-box for "exclusive." If this is selected, each response directed to that bin will be placed only in that bin; if it is not selected, a particular response can be placed in multiple bins. Although there may be other applications for which this is useful, it is designed to allow the instructor to set up a "display" bin of student responses to subsequently show (anonymously) to the entire class for discussion. The responses in the display bin, which would not be marked as exclusive, could also be sorted into other bins. In this way, the instructor can quickly pull together in the display bin responses that are exemplars, that show common misconceptions, and/or that demonstrate novel solutions; these can serve as the framework for rich discussions in building and refining student understanding.

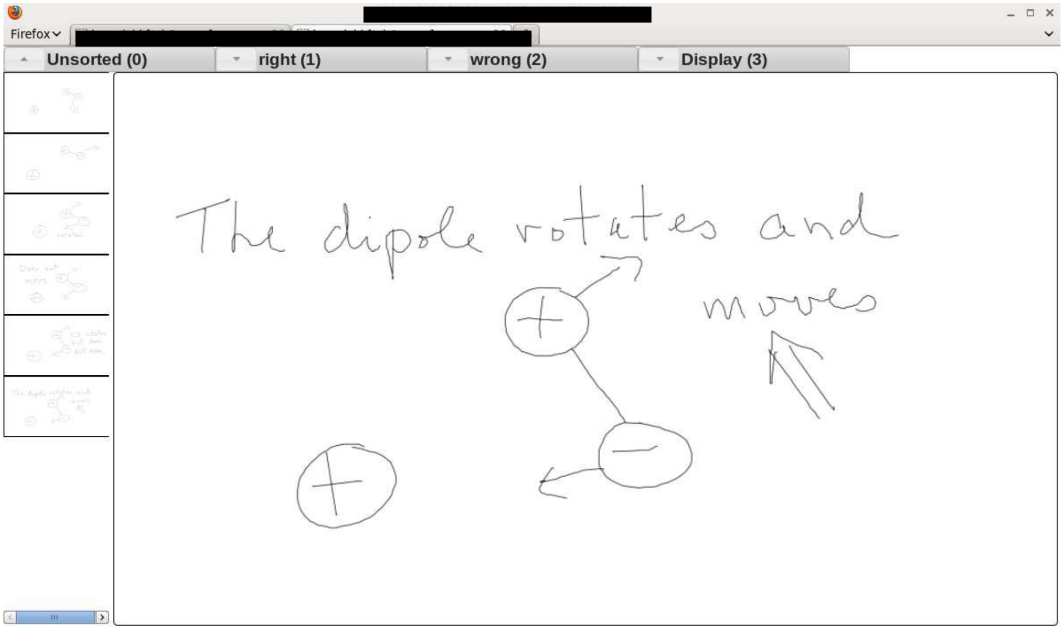


Fig. 1 *InkSurvey* showing the instructor's page, with the sorting feature. The thumbnails on the left show all unsorted responses submitted up to the moment this display was captured (clearly visible in the actual display). In this case, the instructor has set up 3 possible bins to accommodate responses: right (into which 1 response has already been placed), wrong (into which 2 responses have been placed), and a third bin where the instructor can place responses to share anonymously with the class (each response in this non-exclusive bin can also simultaneously be in either of the other 2 bins).

We have found that when instructors use the sorting feature as student responses are received in class, they become much more actively engaged with the responses and feel better prepared to respond in a meaningful way.

Applications in Engineering Education

InkSurvey has been used to facilitate real-time formative assessment in a variety of engineering classrooms. Strong learning gains have been documented in an advanced undergraduate engineering physics course that used *InkSurvey* in this manner; furthermore, those learning gains are not correlated to the learning styles of the students.[18] Similarly, strong gains were reported when *InkSurvey* was used to strengthen problem-solving skills in an advanced undergraduate engineering course.[19] In upper-level undergraduate Chemical Engineering classes, *InkSurvey*'s real-time formative assessment has been effectively coupled with interactive computer simulations to achieve strong learning gains.[20] In an introductory engineering design course[21] as well as both undergraduate and graduate level Food Engineering courses,[22] *InkSurvey* has been successfully employed as part of a larger effort to implement the "How People Learn" framework.

Since real-time formative assessment collected with *InkSurvey* is blind to gender, personality biases, and other stereotypes, it is proving to be a particularly effective tool in group and cooperative learning environments. For example, it has served well as the platform for "electronic brainstorming," where students can anonymously submit ideas to be discussed by the group. When no one is aware of the source of a particular idea, it is easier to focus on the merits of that idea. This also opens the door to additional applications in non-academic settings as well.

The real-time formative assessment facilitated by *InkSurvey* also has potential benefits in engineering education outside of the traditional classroom as well. For example, students could complete a homework assignment outside of class and then shortly before class begins, use their own devices to respond to a question posed by the instructor to probe understanding or identify muddiest points to inform subsequent instruction. This allows simple implementation of the spirit of Just-in-Time Teaching (JiTT) [23] without the need for separate software for its management. Similarly, *InkSurvey* could be used as a tool for gathering real-time formative assessment in the distance-learning environment, allowing the instructor to be more responsive to student needs during the learning process.

Conclusions

Engineering students equipped with affordable mobile computing devices such as pen-enabled Android devices, iPads, iPhones and/or tablet PCs can use digital ink to reveal their thinking during the learning process. As the instructor receives this real-time glimpse into student understanding, instruction can be modified to refine, correct, or reinforce that understanding.

InkSurvey is free, web-based software designed specifically for collecting real-time formative assessment (ticc.mines.edu). Recent improvements have made it more fully functional on a greater variety of devices and more user-friendly for both instructors and students. More versatile grouping and displaying of responses increase classroom utility. Since it is entirely web-based, there is no need for (or advantage to) all students in a classroom having the same hardware; they could, in fact, use their own mobile devices.

The use of *InkSurvey* to facilitate real-time formative assessment is being explored in engineering education. Previous publications describe increased learning gains and improved problem-solving skills when *InkSurvey* is used in the classroom, and enhanced learning gains when coupled with computer simulations. Classroom examples and results presented here reflect student metacognition, how student thinking changes over time, and changes in instructor responses and approaches to learning. *InkSurvey* is also potentially useful outside of the classroom and in non-traditional settings, including distance and group learning environments.

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