Transforming Science and Engineering Classrooms with Online Collaborative Tools

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Abstract
Researchers from the University of Massachusetts Lowell and a non-profit partner, Machine Science Inc., are investigating classroom implementations of a web platform that aids teachers in engaging their students in collaborative inquiry. This technology—the Internet System for Networked Sensor Experimentation (iSENSE)—allows for the contribution of individual student-collected science data to a shared, online repository. iSENSE enables educators and students to initiate their own experiments, contribute data, and then view the data using multiple web-based visualization tools. This paper provides an overview of the iSENSE technology and its use in middle and high school physics, chemistry, and engineering classrooms. The authors worked closely with teachers to integrate data-collection hardware and the iSENSE web software into their existing curricular designs. Teacher interviews and classroom observations were used to study their adoption. Our work indicates that there are multiple, viable paths for integrating iSENSE into classroom science and engineering instruction, and that the technology gives students new, transformative ways of sharing data with one another and learning from that experience.

Perspective/Theoretical Framework
The iSENSE team employs a design-based research paradigm, which Wang and Hannafin (2005) define as “a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories” (p. 6). The design-based approach is well-suited for the iSENSE research because it reflects the practical limitations and advantages of evaluating an educational intervention in real-world classroom settings. Because of its iterative and flexible nature, this type of research benefits from a mixed-methods approach.

Together with teacher and student learning and participation patterns, our research methodology has evolved over the past several years. As the technology and our classroom enactments evolved, we looked for changes in learning as evidenced by data from assessment instruments administered directly to students. Based on this research, the iSENSE investigators have developed detailed case studies of selected classrooms and teachers to generate a textured portrait of individual classrooms, illustrating what aspects of iSENSE are working, and why.
Encouraging students to construct their own explanations from evidence, rather than simply reading or listening to information, has been shown to increase their understanding of scientific topics (AAAS 1993, National Research Council 1996). The process of creating a hypothesis, recording data, interpreting collected data, and coming to conclusions based on findings are agreed upon by researchers as essential elements of “inquiry learning” (Chang et al., 2003).

Scientific probes, along with computer-generated graphics, are used in many classroom experiments to support inquiry learning activities. These probes and their associated software, referred to as probeware, are hands-on data acquisition tools, allowing real-time data collection, storage, and analysis (Marcum-Dietrich and Ford, 2002). Research has shown that science probes, used with computers, can enhance student learning (Zucker et al., 2008). Data collection becomes easier and faster, thus allowing the students more time to think about what their data mean (Russell et al., 2003), as well as allowing them to focus on the variables that affect the results. Students can also run subsequent experiments testing these factors, because it is easy to test their hypotheses (Barton, 1990; Dalphond, 2010).

The iSENSE web system provides a flexible, free, easy-to-use tool for instructors to store and share the data collected in inquiry-based science activities. Data can be manually keyed into the web interface, or data files can be uploaded to the site. In addition, data stored in Google Docs spreadsheets can be examined using the iSENSE web system. The iSENSE team has also created a series of data-logging devices, called Portable iSENSE Network Points, or PINPoints, which feature a range of on-board sensors. Some versions of the PINPoint also incorporate a GPS receiver and connectors for external sensors. The PINPoint is designed specifically to take advantage of the iSENSE web system’s powerful mapping and graphing visualizations, which students can use to explore the data they upload to the system.

**Research Methods**
The case studies presented in this paper were prepared based on research in three different schools, at three different grade levels, in three different subject areas (chemistry, physics, and engineering). Members of the iSENSE technology and educational research teams were present at all three locations during testing. Observations were recorded during the classroom activities, and additional data were collected from teachers after the experiments were run. Classroom observations included questions asked by students, both about the science content and technology, as well as any difficulties they encountered in using the system. These observations were recorded in order to ascertain how effective the tools were in allowing the students to perform their tasks. Following each class session, researchers interviewed teachers to elicit their thoughts on using iSENSE as a learning tool. These interviews explored teachers’ thoughts about students’ science literacy, as well as the strengths and weaknesses of the system.
Case Study 1: Chemistry

A chemistry experiment was conducted with sixth grade students in the northeastern United States. Three chemistry classes taught by the same teacher used the iSENSE materials to run a classroom experiment. At this school, each student had previously taken a computer course in which they learned to use web technology (Google Docs) for homework assignments. Moreover, the use of laptops and tablets was encouraged in several of the school’s classes. A one-day workshop was held at the school to introduce the science teachers to the iSENSE technology. During this workshop, the teachers received hands-on experience with the iSENSE system, learning how to create experiments, contribute data, and create visual representations of the data.

Prior to using iSENSE in their chemistry class, every student in the class received a brief introduction to the system, completing a simple data-collection activity using the PINPoint. Students were asked to walk around the school with the device, while informally taking note of changes in light, temperature, and other conditions that would affect the sensors readings. Once the data were collected, the students uploaded their data to iSENSE, and then used the system’s map, timeline, and scatter chart visualization tools for joint comparison of the data. As a final step, students were asked to “narrate” their data visualizations to their classmates, interweaving recollections of their walk with highlights from the data.

After this introductory activity, students used iSENSE to learn about exothermic and endothermic reactions by recording the temperature changes during a reaction between vinegar and baking soda. For this investigation, students were split into groups of four. The lab setup consisted of a container of vinegar, baking soda, a laptop, and a PINPoint equipped with an external temperature probe. The teacher asked each group to develop a hypothesis. The teacher described a hypothesis to the students as an “if/then” statement, about what was going to happen and when. Some groups hypothesized that “if we add the baking soda, then the mixture will fizz and heat up,” while others thought that the solution would cool down. Students were told not to be concerned about providing the right or wrong answer, only to focus on trying to prove or disprove their hypotheses.

Each group ran the experiment independently. First, students placed the temperature probe into the cup of vinegar and started recording the temperature. The students then added the baking soda to the vinegar and continued to record the temperature of the reaction for one minute. Each group then uploaded their data to iSENSE and used the visualization toolkit to look at the data and analyze the validity of their original hypothesis. The students were given time to come to their conclusion while still in groups. Students were observed graphing the data using both the scatter chart and timeline visualizations. Based on these graphs, each group was able to determine whether they had correctly hypothesized what would happen during the baking soda-vinegar reaction. The teacher then led a group discussion, encouraging each group to give an explanation of what they had observed. Figure 1 presents three data sets collected by three different student groups graphed together using the iSENSE timeline visualization. This graph was used during the group discussion.
In previous years, the teacher had run a similar experiment but had asked students to plot their data on paper. The teacher mentioned that the hand plotting had taken up most of the class period, leaving little time for analysis. Because iSENSE automates the data plotting, each class had 20 minutes remaining after one full cycle of data collection and analysis. In all three classes, the students wanted to run the experiment again. The teacher agreed, asking students to vary the quantities of the reactants to explore whether this would affect the reaction. Each group was given a different amount of baking soda and asked to run the experiment again. The students were asked to compare their results from the first experiment to the results of the new one. Without further instruction, the students were able to create visualizations of data from both trials, enabling direct comparisons. By examining the slope of the lines on the scatter chart and timeline visualizations, the students were able to determine that there was a difference between the two. Comparing their data between groups on a projector at the front of the classroom, students were able to identify the effect of using different quantities of reactants on the temperature curve.

Three main observations emerged from this classroom work. First, several students in one of the classes had not been present for the training the day before. These students were divided into the other groups of students that had been present. The trained students were able to easily explain the tools and the website to the untrained students during the experiment process. The second observation was the power of jointly visualizing all data on the main screen. This led to a detailed discussion about what had happened, giving the students a better understanding of the material. Lastly, the teacher was pleased that the use of iSENSE had saved class time by allowing the students not only to finish the required lab, but also to extend the experiment.
In a post-experiment interview, the teacher indicated that the system was both easy to use and straightforward to integrate into her curriculum. The teacher was encouraged by the fact that students were not required to hand-graph all of the data that they recorded. As this was a chemistry class, graphing abilities were assumed. This allowed the students to extend the experiment, which she felt gave the students a deeper understanding of the material. Finally, the use of the technology made the students feel as if they were in a real laboratory, which she thought increased science literacy in her class.

Case Study 2: Physics

In the second case study, high school students from the northeastern United States used iSENSE to collect, upload, and store acceleration data while taking rides at an area amusement park. The teacher who devised this activity had attended several professional development workshops at UMass Lowell at which iSENSE had been presented and had prior experience using the system. The teacher was interested in seeing how iSENSE technology, and in particular the use of an application on a mobile device, could be used to enhance the activity. Members of the iSENSE research team were present during the collection of all data to observe how the students interacted with the mobile application, as well as during subsequent data visualization and analysis in the classroom.

The data-collection activity took place during a day-long field trip for “Physics Day” at an amusement park. In previous years, students had collected observational data throughout the day and had completed worksheets to examine the forces experienced on each ride. With the help of the teacher, we modified this activity so that the smartphones were used as sensors and data collectors. The teacher designed a schedule for the day, requiring students to bring the smartphones on rides to collect data. Before going on the rides, students were given smartphones and runner’s arm bands to secure them. Students received specific instructions on how the smartphones should be worn on their arms and how they should hold their arms during the rides. (Maintaining consistent arm and phone positions helped ensure that the orientation of each of the accelerometer’s three axes would be consistent from ride to ride.) The teacher showed the students how to start and stop data collection. The smartphone app collected acceleration and location data throughout the duration of the ride, and the data were later uploaded the data to the iSENSE system.

The goal of this learning activity was to give students a chance to “feel” the effects of free fall and centripetal acceleration while collecting real accelerometer data. Data were collected for four rides: Cannonball (roller coaster), Turkish Twist (single-axis spinning), Starblaster (vertical lift and free-fall), and Zero Gravity (multi-axis spinning).

The students used the data in an in-class assignment. The teacher provided students with a four-part worksheet, which they completed before viewing the data they had collected. The first part of the worksheet asked students to think about potential causes of error in the data. On the second and third parts, students described the ride for which they collected data and identified phases where interesting patterns in the data had emerged.
After completing the first three sections of the worksheet, the students were given several demonstrations with the smartphones. The teacher recorded data while the phone was in free fall and while it was experiencing centripetal acceleration. These demonstrations were performed to show the students what data from the smartphones looks like under certain circumstances. The students then used that information to complete the fourth section of the worksheet. The students had to draw a graph representing what the data would look like on the ride. These graphs were called “prediction graphs,” and were later presented to the class. Figure 2 depicts a student’s prediction graph compared to a graph of the actual data collected and graphed on iSENSE.

![Figure 2. A student’s prediction graph vs. actual data graphed on iSENSE](image)

Only after the prediction graphs were completed and presented did the students see the real data they had collected. Prior to the students completing the worksheet, the teacher and researcher selected the “best” data set from each ride. This data set was determined based on what the team expected the data to look like. A good data set consisted of data that followed an expected trend. The selected data sets were uploaded to iSENSE in a special experiment, where the identity of the ride was hidden. These data sets were presented to the students without any context, and the students had to determine which ride the data represented. During this part of the activity, the students began a thorough discussion of the data. Even on rides that the teacher and researcher thought would be obvious, the students noticed incorrect values and mistakes in the data that made them reconsider their initial interpretation. After revealing the identity of the ride to the students, the teacher showed them the combined data for the ride, which helped the students determine what may have caused errors in the data.

After the activity concluded, the teacher was asked to reflect on the activity. One of the first things the teacher said was that this activity could not have been performed with other probeware. Of all the technology the teacher had available to him, including the PINPoint and Vernier probes, none would have been as effective as the smartphones. Smartphones are more durable than other solutions as they are designed for everyday use. According to
ComScore (2011,2012), in 2011 approximately 70 Million Americans had smartphones, 6.8% of which were ages 13-17. With over 4.7 million high school aged students using smartphones already, leveraging this prior training with the tools was of great benefit. The smartphones were easy enough for the students to use, providing visual feedback when data were recorded, and sensitive enough to collect useful data.

The teacher also thought that the use of iSENSE to visualize the data lead to a more in-depth discussion of the data. The iSENSE system's ability to graph multiple sets of data at once made it easy for him and his students to compare all of the data they collected. Also, because iSENSE is web-based, the students had access to the data outside the classroom. They were able to view and manipulate the data on their own, while writing up their summary reports. Overall, the teacher felt that the use of the smartphones and iSENSE had a large contribution to the students' overall understanding of the concepts.

**Case Study 3: Engineering**

The third study is based on an engineering class at a technologically advanced high school. One of the teachers involved in this study had attended a workshop run by the iSENSE team and had requested the use of the system in his school. Over 90 students from the grade 10 classrooms of three different teachers participated in an activity to find the most effective windmill design. None of the students, and only one of the teachers had used iSENSE before. Each student took a picture of their windmill design, which they linked to the data collected. This experiment was run as a competition, providing incentives for students to iterate quickly through the design, build, and evaluation process.

The students that participated in the activity worked in groups of three. Each group was provided with a standard base for their design -- a simple PVC structure with a DC motor and a hub for mounting student-made windmill blades. Students designed blades, which were inserted into the hub. To build their blades, students chose from several different materials, such as wood, cardboard, and paper. Their designs could incorporate up to twelve blades, in any size or shape, and mounted at almost any angle with respect to the air flow.

Once each student team had a design that was ready to be tested, they would attach the blades to the DC motor. The motor was connected to a Vernier voltage probe, which was connected in turn to a laptop computer running Vernier Logger Pro. The students placed their turbines one meter away from a standard house fan. Each trial ran for 30 seconds, with the students starting the fan at the low setting, then after 10 seconds changing it to medium, and finally after another 10 seconds changing it to high. Logger Pro recorded and graphed the data in real time and exported the data as a CSV file.

After data were collected, the students contributed their data to an experiment on iSENSE. The students took a photograph of their design and created a new session for their data, attaching the photograph to their session. This allowed them to not only see how the design performed, but also have a visual record of the design. Students tested several different designs trying to
find the most effective one. As they uploaded more sessions to iSENSE, they could combine the
data and view each design at the same time. By viewing the all their data at once the students
could easily determine which design was the most functional. They could then reference the
photograph of their design to re-create it. Figure 3 shows a student’s windmill and its associated
power generation graph.

Figure 3. A power generation graph and corresponding student built windmill. The graph
shows the increase in voltage as wind speed was increased.

Once the students decided on their best design, they entered it into the contest. The contest
involved the same setup; however, the experiment was more closely supervised. Each entry
was tested using the same fan to source the wind, operated by the teacher. Once again, Logger
Pro was used to collect the data for the experiment. After the experiment was run, the teacher
outputted the CSV from Logger Pro, took a picture of the design, and uploaded it. The iSENSE
system was then used to compare the results and find the best design.

The teacher commented that he observed the students comparing their results with those of
other students in different classes. Many had a keen interest in their own windmill’s performance,
and in comparing it to that other students’ designs. The cross-classroom comparisons were
facilitated by the iSENSE web system, and had not occurred in previous work done by the
teacher. The students also discovered that there was not a single best design. One of the
unexpected results was that some designs performed better at low wind speeds, while others
performed better at high wind speeds.
Results
The data collection in each of the use cases discussed was done with different techniques. In the chemistry study, students worked in a classroom/laboratory setting and used custom sensors to collect data. In the physics study, students used Android phones to collect data in the field, and analyzed data in the classroom. In the engineering study, students built model windmills in a classroom/laboratory setting and used Vernier technology to collect data. In all three studies, students’ data collection was successful, and their data were able to be uploaded into the iSENSE system. Students and teachers in the physics and chemistry studies analyzed the results and discussed their findings in the classroom, and the engineering students did this work as an at-home assignment.

In these activities, the use of iSENSE facilitated more questions, and supported in-depth discussions when analyzing the data. For instance, in the chemistry study, the students were able to conduct a second experiment (because iSENSE allowed them to analyze their data quickly), and in that second experiment, were able to compare a whole classroom’s worth of variances on the core experiment.

In many school science experiments, students are expected to adjust parameters and run an experiment a few times, hoping to discover which parameter causes which experimental outcome. This is often difficult to accomplish, because students have only enough time to try their experiment with a few combinations of parameters. Then, the intended relationship is hard to demonstrate, because of measurement error in any one experiment, or the need to have far more than a few trials before a relationship between parameters and outcomes becomes clear. In contrast, when using iSENSE, all students in a classroom (or a larger workgroup) can contribute their results to a central location, thereby learning from each others’ work. In the case of the chemistry study, students were able to determine a relationship between concentration of baking soda and chemical reaction rate in this fashion.

In certain cases, the iSENSE hardware tools were superior to commercial sensors. This was particularly so in the physics study; the use of Android phones for collecting acceleration data was considered by the classroom teacher to be superior to commercial offerings.

Overall, use of the iSENSE system was shown to help engage and encourage students to explore their data in multiple scenarios. iSENSE successfully contributed to learning activities outside of the classroom, as well as in the classroom. The teachers involved were enthusiastic about the contribution to their students’ learning that they were able to accomplish with iSENSE, and they plan to continue its use in their classrooms.

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