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Real-World Problem-Solving Using Real-Time Data*

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Preparing tomorrow's workforce of engineers requires that today's K-12 students learn how to become better problem solvers. This can be accomplished by engaging students in authentic, complex problems that are relevant to the world around them. Use of real-time data provides a dynamic, real-world context in which opportunities can be created for students to handle open-ended, age-appropriate problems in engineering and so obtain the experience that will better prepare them for their chosen profession.

Keywords: engineering; pre-engineering; education; problem-based learning; real-time data

BEYOND THE CLASSROOM

SOLVING REAL-WORLD problems is a central aspect of engineering practice, and is an important part of engineering education. Real-world problems differ from typical textbook problems in many ways: they are ill-structured, contain multiple, often conflicting goals, are dynamic and often require collaboration with engineers and non-engineers [1]. They are certainly more difficult to implement in a classroom setting than are typical textbook problems and not so easily assessed. However, these real-world problems can engage students in deeper cognitive processes more akin to those of practicing engineers. Learning how to find meaningful solutions to real-world problems not only provides K-12 students, who are not typically exposed to any formal pre-engineering curriculum, with an authentic context for science and mathematics principles, but also offers a glimpse into the world of engineering, about which they may know very little. One vehicle to introduce the complexity of real-world problems into a classroom setting is through the use of real-time data from online databases.

The Center for Innovation in Engineering and Science Education (CIESE) at Stevens Institute of Technology has developed online curriculum materials for K-12 students that do just that. These online projects promote problem-based learning through the integration of science, mathematics, technology and other core subjects. The projects are explicitly linked to national content standards and are multi-disciplinary, focusing on science and mathematics topics that require quantitative analysis, critical thinking, collaboration and other 21st century workforce skills [2].

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These types of real-world projects create opportunities for students to hone their creativity and collaborative and critical thinking skills as they tackle problems for which the solution is not predetermined. By incorporating real-time data into the projects, students are faced with solving a realistic problem whose solution is not predefined. It provides the authenticity, and sometimes even excitement, that no textbook, teacher or case study could.

HOW WE ARRIVED HERE

According to the Science and Engineering Indicators [3], there is serious concern about the long-term trend of decreasing numbers of students completing bachelor's degrees in engineering. The number of students earning such degrees dropped by 30% between 1985 and 2000. In 2000, less than 5% of those earning bachelor's degrees were in engineering disciplines. In addition, females and minorities have not been completing degrees in engineering at the same rate as males and other groups. The decreasing numbers of students completing degrees in engineering could have a serious effect on the science and engineering workforce of the United States unless more sufficiently prepared students, especially females and minorities, begin studying engineering in college [4]. There is an urgent need to excite and attract students to engineering. In addition, business, since the landmark SCANS report [5], and more recently other groups [2, 6, 7] are calling for students' mastery of 21st century workforce skills: information and communication skills, including the ability to access, analyze, evaluate and synthesize information and to communicate effectively by mouth, in writing and using multimedia tools; thinking and problem-solving skills, including problem identification, formulation and solution, as well as intellectual curiosity and creativity; also interpersonal and self-directional skills [6]. These skills are particularly important for future engineers, as documented in the National Academy of Engineering's *The Engineer of 2020* [8]. Also of critical importance in the contemporary workforce are such technological literacy skills as designing, developing and utilizing technological systems; working collaboratively on problem-based design activities; applying technological knowledge and ability to real-world situations [9, 10]. These skills are increasingly recognized by business, higher education and policy leaders as critical for tomorrow's workforce [11].

Similarly, the need to improve science achievement in US schools is well documented [12, 13]. Progress toward increased levels of proficiency can result from student engagement in robust problem-solving activities that incorporate the use of real-time data. This approach, advocated by the American Association for the Advancement of Science, National Council of Teachers of Mathematics and the National Science Education Standards, is a powerful 'avenue through which students can increase their science and mathematics literacy' [14]. Given the dramatic NAEP Science findings of 2000 which showed a statistically significant increase in scores of eighth- and twelfth-grade students who reported using computers to collect data, download data, or analyze data compared to students who reported never doing so, there also exists compelling evidence that this approach to science instruction can improve standardized test scores [13]. Despite these developments and the fact that the Internet is now available in all public schools in the United States [15], only 27% of teachers engage students in activities that involve using computers or the Internet to 'solve problems and analyze data' to a large or moderate extent [16].

For many science teachers, assigning students large numbers of problems is seen as an ideal way to improve problem-solving skills and conceptual understanding [17]. It can therefore be surprising when their students' ability to solve new problems does not improve [18, 19]. Recent research on the differences between novice and expert problem solvers can help shed light on this puzzle. Expert problem solvers tend to conduct qualitative analysis of problems, using big picture or core concepts and underlying principals, before executing the quantitative solution [19]. In contrast, novices will approach problems by searching for correct formulas, often 'manipulating equations that contain the quantities given in the problem until they isolate the quantity of variable being asked for' [19]. Unfortunately, since textbooks do not tend to emphasize skills and techniques needed for expert problem solving, it should not be a surprise that students have difficulty applying these skills in novel, open-ended, or complex contexts.

The use of curricula that include relevant real-time data can improve student achievement and promote higher order thinking, critical analysis, collaboration and problem-solving skills. Use of online projects that incorporate real-time data in problem-solving activities may take more planning time on the part of a teacher, but ultimately result in students covering a multitude of content and process curriculum standards in an engaging and relevant way [20]. These web-based inquiry activities often use the same real-time data and information used by actual scientists and thus permit students to approach larger, more complex and authentic investigations [21]. In a study of one real-time data project used by middle and high school teachers, 50% of the teachers using this online project reported that the aspect they liked most about the project was that it had lessons that used real-time data or had real-world applications [22]. Additionally, student interest and motivation increases when using real-time data projects, especially when they are able to collaborate and share results with other students using the same online projects in other parts of the world [23].

INSTRUCTIONAL CONTENT

The Center for Innovation in Engineering and Science Education (CIESE) at Stevens Institute of Technology began collaborating with K-12 schools and teachers on exploring compelling applications of Internet-based resources in science and mathematics education in 1993, just before web browsers such as Netscape and Internet Explorer became pervasive. Through a $2.9 million National Science Foundation Networking Infrastructure in Education grant, Stevens collaborated with more than 3,000 teachers from 700 schools throughout New Jersey, and, through this programme, developed both a position regarding the effective use of the Internet in K-12 science and mathematics education [24], as well as a portfolio of curricular resources that utilize what has become known as 'unique and compelling' Internet applications for science and mathematics education. These applications offer unique educational opportunities beyond more static types of instructional tools, such as textbooks or even CD-ROMS and simulations, as well as compelling educational benefits, such as the ability to engage students in dynamic, real-world problems. The use of Internet-based real-time data is one powerful example of a unique and compelling application of the Internet which is being used effectively to provide students with problem-solving opportunities that are similar to the engineering problem-solving process. These instructional tools provide a dynamic set of ever- changing data that provide authenticity, complexity and a real-world context. Consider the topic of vectors in a typical high school physics course. All physics classes touch on this topic at some point in the curriculum. For most students, this means solving a multitude of traditional textbook problems including those that involve

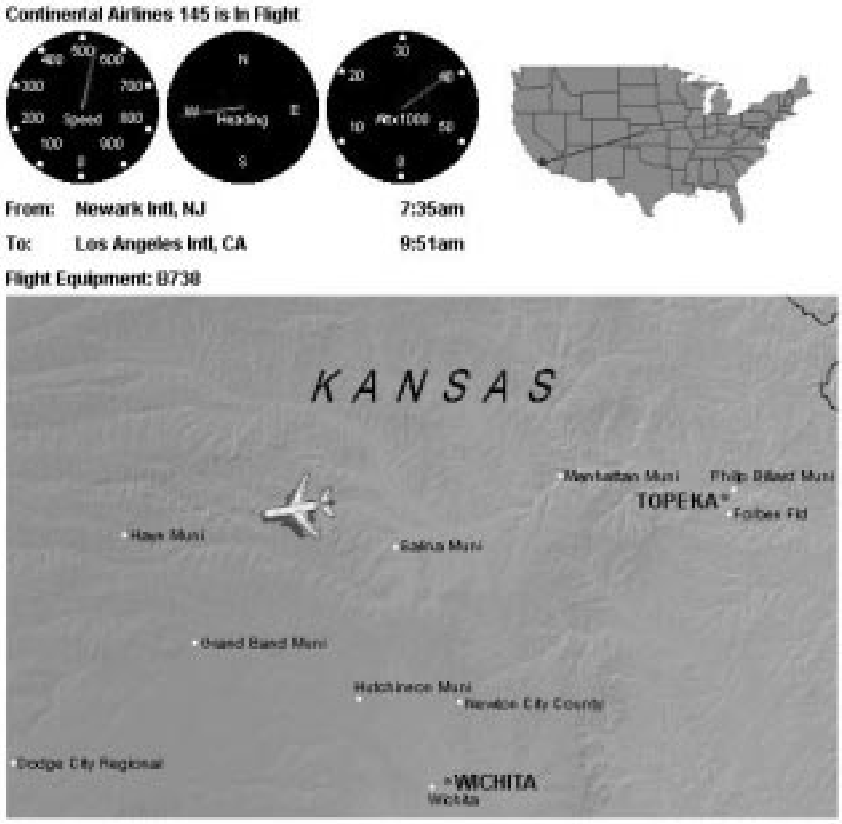

Fig. 1. Example of Real-time Flight Information

airplane flight. As an alternative to this type of novice problem-solving, students using the online *Navigational Vectors* project learn how to do vector analysis by analyzing real-time flight data of airplanes currently flying in U.S. skies (Fig. 1) and the corresponding real-time wind data in the plane's vicinity. After completing calculations that serve as an introduction to vector analysis, students are faced with the problem of landing a plane because of a medical emergency. Students must use up-to-the minute flight and wind data, along with other information such as plane size and locations of nearby airports and hospitals, to solve this real world problem. Since there are no right and wrong answers, students must justify decisions based on their analyses and the information they have available to them. Students write up a 'Pilot's Incident Report' documenting what happened and why they made certain decisions. Using visual aids and explaining any necessary physics concepts, they present their report to their classmates and teacher.

Over the course of this unit, students cover the following physics concepts:

- Displacement;
- Velocity;
- Scalars and vectors;
- Vector addition—graphical and analytical;
- Frames of reference;
- Relative velocity;
- Vector Applications.

These concepts are common in any high-school physics curriculum and meet national science, mathematics and technology standards. What is different is that the *Navigational Vectors* project provides the opportunity for students to engage in concept-based problem-solving within a framework of multiple real-world contexts.

An example of an authentic, problem-solving project at a middle grade level is *The Stowaway Adventure*. Students take on the role of a stowaway aboard a ship at sea and need to figure out their current location, speed and direction in order to predict the port-of-call to which they are headed and their estimated time of arrival. They track and predict the course of an actual ship at sea by accessing real-time data that includes latitude and longitude coordinates of their ship at various time intervals. Students are able to track their ship over a period of days to see if their predictions prove to be accurate (Fig. 2). Examination of real-time weather information in the vicinity of the ship using satellite and radar images along with wave height and direction data give students a picture of the local weather conditions surrounding the ship. As part of this project, students learn how to solve basic speed and direction problems which they could do just as easily by solving standard textbook problems over and over again. However, students also learn that in the real world, problems usually have many different aspects and variables. When students observe their ship suddenly veering off-course, they look for reasons why this

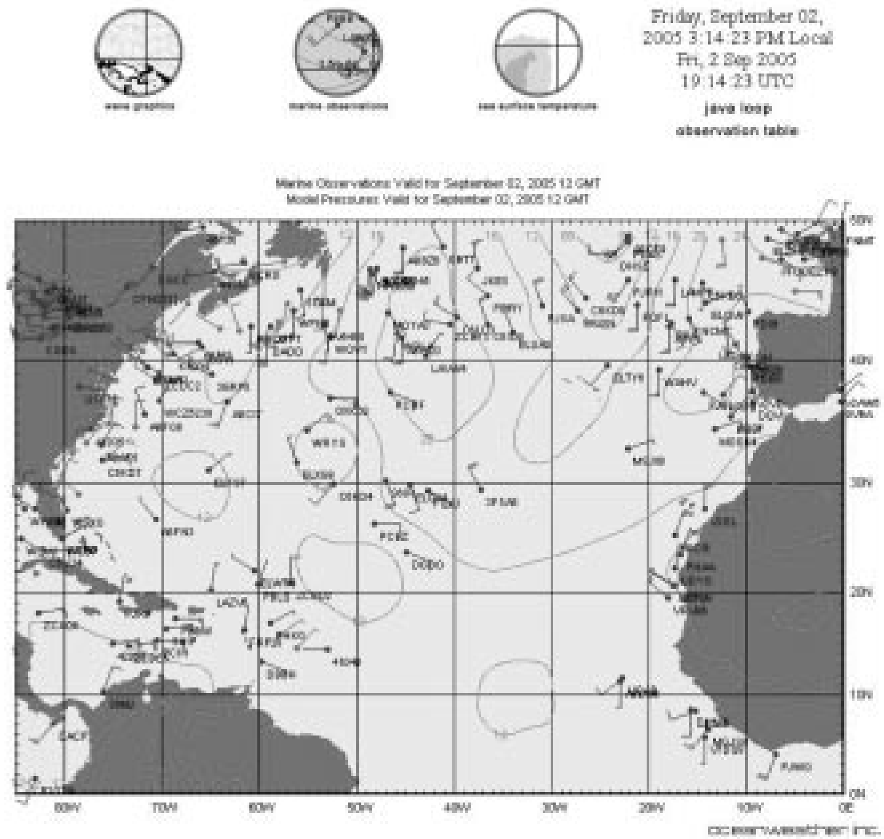

Fig. 2. Real-time Ship Locations in the Atlantic Ocean

might have occurred such as impending weather conditions, other nearby ships or land mass. Students are challenged to make new predictions based on continuously updated information. The problems students are exposed to in this project are not simple with a single solution. They are engaging, multi-disciplinary, real-world problems that can change and have a variety of solutions.

Other CIESE projects that incorporate the use of real-time data in problem-solving include projects using real-time weather data, earthquake data and air pollution data, among other data sources (Table 1). For each project, a scenario is provided that sets the context for the problem and defines exactly what the students are asked to do. The underlying goal of each of the projects is to provide an authentic learning opportunity that connects students to the world beyond the classroom. Each year, more than 100,000 students around the world participate in CIESE Internet-based projects. CIESE provides online support to teachers and students during the implementation of these projects and provides professional development to teachers for how best to incorporate these types of projects in their current science and mathematics curricula. All online projects are available at http://www.stevens.edu/ciese.1

IMPACT ON LEARNING

Two analyses have focused on measuring the impact of the use of the Stevens real-time data and telecollaborative projects on student achievement. While the studies were not explicitly intended to measure problem-solving abilities, they do suggest a positive impact on student learning of science and mathematics content and process skills and students' use of technology in solving real-world problems and in creating products. A 2002 Student Impact Study (SIS) by Harcourt Education Measurement showed statistically significant gains in students' science and mathematics learning, measured via pre- and post-tests, among elementary, middle and secondary-level students using Internet-based real-time data and telecollaborative projects (Table 2) [25]. In addition, Yepes-Baraya concludes that in the classrooms studied, 'By emphasizing inquiry and the collection and analysis of data, students were encouraged to stay active and engaged in learning . . . Multiple technology tools and resources were available for student use. At every level (elementary school, middle school, and high school), students were observed using or learning to use these tools and resources effectively [25].' The second analysis focused on the impact of

Table 1. Examples of Real-time Data Projects

Project	Description	Grades/Subjects
Navigational Vectors	Students track a real airplane in flight and learn how vectors and trigonometry are used for aviation navigation.	Grades 9–12 Physics Mathematics
Musical Plates	Students use real-time earthquake data to explore the relationship between earthquakes and plate tectonics.	Grades 6–12 Earth Science Social Studies Language Arts
The Stowaway Adventure	Students use live remote sensing data from ships at sea to find a ship's speed and course heading. They predict its destination and estimated time of arrival. Focus is on math concepts and navigation.	Grades 5–8 Mathematics Physical Science Earth Science Language Arts Social Studies
The Gulf Stream Voyage	Students use real-time data and primary source material to discover the science and history of the Gulf Stream. Students investigate the driving forces behind this great ocean current and how it affects the Atlantic Ocean.	Grades 6–12 Marine Science Earth Science Chemistry Physics Physical Science Biology Mathematics Social Studies Language Arts
Wonderful World of Weather	Students investigate weather phenomenon around the world and learn how weather can be described in measurable quantities.	Grades K-6 General Science Earth Science Language Arts
Air Pollution: What's the Solution?	Students use real-time and archived air quality data to discover the causes and effects of ground level ozone	Grades 6–9 Earth Science Environmental Science Chemistry Health
Weather Scope	Students use hands-on activities and real-time data to study factors that affect weather and climate.	Grades 5–10 General Science Earth Science
Catch a Wave	Uses real-time data to guide student discovery of the causes and effects of ocean waves and tides.	Grades 6–12 Earth Science General Science Marine Science

Table 2. Student impact study pre- and post-test results

	Ms Young Cleveland	Ms Castillo Miami	Mr Herman Phoenix
Grade	3	10-11	7
Number of Students	24	29	25
Project implemented	Wonderful World of Weather	Global Water Sampling	Stowaway Adventure
Source of Evidence	Student Pre-Post Test Comparisons (paired t-tests)		
Mean pre-test score (%) (SD)	19.7 (6.4)	10.8 (15.8)	31.2 (27.7)
Mean post-test score (%) (SD)	54.1 (11.1)	44.8 (23.7)	50.4 (16.9)
Gain (% points)	34.4	34.0	19.2
N (valid cases)	20	29	22
Probability	0.0001	0.0001	0.001
Statistical significance	Yes	Yes	Yes

use of middle school-level real-time data and collaborative projects on student achievement on the Grade Eight Proficiency Assessment (GEPA) in an educationally and socioeconomically disadvantaged district of 43,000 students in urban New Jersey. In a report to the NJ Commission on Higher Education, the assistant superintendent attributed 'dramatic increases in students' science achievement scores averaging 10% growth sustained over three years—in those schools that worked with Stevens in this program [26].' The project evaluation report also concluded that the project increased the incidence of authentic learning through technology integration [27].

CONCLUSION

Preliminary evidence suggests that positive impact on student learning of science and mathematics content and process skills—of which problem-solving is one important element—can result from use of real-time data as part of science and mathematics problem-solving. Use of real-time data provides a dynamic, real-world context that provides opportunities to create open-ended, age-appropriate problems that provide students with experiences to prepare them for solving engineering problems. Further, as K-12 educators increasingly strive to integrate 21st century workforce skills into classroom experiences, and as society increasingly recognizes the need to foster creativity, design, and problem-solving abilities among *all* students, not merely those who self-select to pursue advanced STEM study, the use of authentic, real-world problems using real-time data, will likely be an invaluable resource. Therefore, more focused research on the learning effect of real-time data on student problem-solving abilities is needed. Such real-time data projects using dynamic, Internet-based resources satisfy the need for new standards-based instructional materials that can be used for K-12 engineering education, and a number of such resources are being compiled, including the 'Living Laboratories' curricula that are part of the TeachEngineering.com web site [28]. Not only do they provide problem-based learning opportunities for students, they tap into the uniqueness of the Internet to deliver real world and real-time data thus making the problems more engaging and relevant.

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