Use of Personal Digital Assistants in Assessing the Problem Solving Process

Tuba Pinar Yildirim, Mary Besterfield-Sacre, and Larry Shuman, Member, IEEE

Abstract—We demonstrate how mobile technology tools such as personal digital assistants (PDAs) can be used for educational assessment. Specifically, we use PDAs to assess the problem solving process in special modeling exercises known as Model Eliciting Activities (MEAs). We record the problem solving process used by engineering students with PDAs and assess the process by investigating (1) teamwork, (2) how students iterated among the problem solving steps, and (3) how they divided their time among tasks. Results suggest that process characteristics measured by PDAs and the problem solving outcomes are related. We found that higher performing students worked as a true team (as opposed to groups or individuals); had solution processes that tended to be linear (i.e., most students worked on one task at a time and did not iterate back to prior steps); and spent time on each phase of the problem solving process.

Index Terms—Model Eliciting Activities, PDA, Problem Solving, Teamwork

I. INTRODUCTION

With engineering education becoming more complex, handheld computers have proven to be a valuable instructional resource, as they offer a powerful and portable means of managing information. The most commonly used of these tools is personal digital assistants (PDAs). They have been used in the classroom for formal instruction, including such applications as conducting real-time surveys, tests, quizzes, and questionnaires, all of which help the instructor monitor the process of learning. Not surprisingly, the use of PDAs has grown in engineering schools nationwide. Combined with the increasing use of smart phone technologies, many PDA applications may gain speed in implementation.

The goal of this study is to demonstrate how PDAs can be instrumental in recording student process data, which can then be used for assessment. In particular, we are using data collected through PDAs to analyze the relationship between the recorded student problem solving process and its outcome. Similar analyses to the ones presented in this paper can help instructors gain an insight into student problem solving that s/he would otherwise have no means to observe.

In recording the problem solving process of students, we have used a special type of exercise called Model Eliciting Activities (MEAs) [1]. Model Eliciting Activities are open-ended, thought revealing engineering cases that are built on a specific structure simulating real life problems. We collected data on the problem solving process by recording students’ self-reported tasks through programmable PDAs. While student teams were working on the assigned MEA, the PDAs prompted individual students at set intervals (e.g., every 10 minutes). Upon prompting, each student entered the particular problem solving activity that s/he was engaged in at that time. This type of sampling enabled us to obtain a valid statistical description of the process. Next, using data obtained in this manner, we analyzed the process of engineering student problem solving and how particular characteristics of the process affected the outcome.

Results suggest that there are significant relationships between the process characteristics measured by the PDAs and the problem solving outcomes observed. We find that when students worked in teams, they achieved higher scores on their artifacts (solutions). Hence, in our study, working in teams (i.e., all members working together on the problem) as opposed to working in groups (i.e., individuals working with some members of the team, but not all together) or working individually had a clear advantage in the outcomes of solving modeling problems. In addition, the data indicated that the solution process of student engineers is mostly linear, i.e., students work on a single task at a time and do not iterate back to a prior step once they have completed that step. This result suggests that iteration in problem solving (a desired ability) may be rare among engineering students. It is also possible that the MEAs used in this study do not require much iteration during solution. Finally, we have investigated the time that students allocated to different phases of a model building

Manuscript received June, 30 2010. This research is supported in part by the National Science Foundation through DUE 071780 (University of Pittsburgh): “Collaborative Research: Improving Engineering Students’ Learning Strategies through Models and Modeling.”

Tuba Pinar Yildirim is with University of Pittsburgh, Swanson School of Engineering, Pittsburgh, PA 15261 USA (412-624-9850; fax: 412-624-9831; e-mail: tyildirim@katz.pitt.edu).

Mary Besterfield-Sacre is with University of Pittsburgh, Swanson School of Engineering, Pittsburgh, PA 15261 USA (e-mail: mbsacre@engr.pitt.edu).

Larry Shuman is with University of Pittsburgh, Swanson School of Engineering, Pittsburgh, PA 15261 USA (e-mail: shuman@engr.pitt.edu).
exercise (namely, the initiation, problem solving and finishing phases).

Generally speaking, we have observed that allocating equivalent time to each problem solving phase pays off. In other words, students seem to earn higher grades if they devote approximately the same amount of time to:
- understanding the problem and search for a solution,
- solving the problem, and
- evaluating and writing up the results.

In the following sections, we provide background on PDA use in classroom, problem solving process, computer supported collaborative learning systems, and MEAs. Next, we describe the methodology and present results of the problem solving process analysis obtained with PDAs. We conclude by providing recommendations for practitioners on the use of PDAs and suggest that the findings can be extended to smart phone technologies.

II. BACKGROUND

A. Personal Digital Assistants (PDAs)

PDAs have been in use since the early 1990s. In certain areas such as education and medicine, PDAs are widely used in practice. This ranges from use in formal course instruction, to planning and organizing schedules, recording and storing data, and accessing and disseminating information. Studies investigating the potential use of PDAs as learning tools have been conducted within K12 settings [2]-[4], as well as at the college and university level [5], [6]. PDAs have a great potential for providing students with a tool that can support learning in various contexts. Sharples [7] proposes that PDAs can also be useful as lifelong learning tools, since such tools accompany learners throughout their lives, and are used to input data and access information whenever the learner feels it is necessary. In this way, portable devices would become lifelong learning tools that release the learner from constraints imposed by desktop computers. PDAs also provide support for distance education, providing access to learning resources anytime and anywhere.

B. Problem Solving Process

Problem solving ability is a characteristic of successful engineers. Several definitions of problem solving exist. Problem solving is a decision-making process that occurs when a solver is presented with a task for which s/he has no specific set of actions that could be used to reach a solution [8]; it is finding an appropriate way to cross the gap between where you are and where you want to be [9]; and is the process of moving toward a goal when the path to that goal is uncertain [10].

Researchers have been working on understanding how students solve problems for decades. One of the earliest problem solving process analysis was created by Polya [11]. According to his four steps, in How to Solve It, the solver summarizes known and unknown information, introduces suitable notation, and draws a figure. Next, the solver uses his/her knowledge to plan how to connect the given data to the desired goal. Then s/he implements the solution by carrying out the necessary procedures to reach an answer while checking his/her work along the way. The final step is looking back, or examining the result to verify that it makes sense, and if possible using an alternate procedure to validate the answer.

In this study, we have expanded the categories of problem solving, using the following task labels that are based on the previous teamwork literature stemming from Polya:
- problem identification,
- problem statement formulation/ modeling,
- data collection and experimenting,
- interpreting the results,
- documentation and referencing/ reviewing,
- non-productive activities, and
- other (i.e., coder cannot define a step).

Earlier work indicated that using problem based learning (PBL) cases provide students exposure to and practice at problem solving that translates into higher scores on authentic assessments of these skills [12]. We use MEAs in this research to create a link to problem solving similar to that of PBL.

C. Computer Supported Collaborative Learning

A stream of studies that aim to help improve and analyze problem solving using computer supported collaborative learning (CSCL) exists. An advantage of a CSCL environment is controlling the computer-mediated interaction. Some studies focus on human-computer interactions [13], while others focus on investigation of tasks [14], [15]. More recent models put emphasis on group-oriented tasks [16] and dialogues and their implications of different communication layouts. Other successful CSCL methods include situated learning perspectives and involve students in “guided” collaborative activities. The idea of a situated approach is that the learning situation should resemble the application as closely as possible.

Our current study is different from the CSCL studies in the sense that the computer or PDA intervention is minimal and is only used to record the characteristics of the problem solving process. It is not aimed at changing or supporting the process itself. Therefore, computers are only a mechanism to record and assess collaboration, rather than an approach to guide or structure it. However, it can be recognized that if students are prompted periodically on the problem solving process it could influence them to meta-cognitively think about the process. Another important distinction is our approach in collecting data from individuals and interpreting them altogether to determine the group activity. This approach is relatively new and offers an alternative way to assign the team characteristics.

D. Model Eliciting Activities (MEAs)

An MEA is a thought-revealing, model-eliciting, open-ended, real-world, client-driven problem and a learning and assessment tool that is adapted to engineering [17]. MEAs
were originally developed by mathematics education researchers to better understand and promote problem solving by encouraging students to build mathematical models in order to solve complex problems. MEAs were also built to provide a means for educators to better understand students’ thinking. These problems involve an individual assignment and a group assignment part to be solved by the students. For more information and examples on MEAs, readers can visit www.modelsandmodeling.net.

III. METHODOLOGY

A. Demonstration of PDA Use to Collect Data

To analyze problem solving patterns, we have used personal digital assistants (PDA) to collect data. At specific time intervals when solving the MEA, students were asked to record their current task. To record the process, we utilized UMT software (v. 16.7.2, 2007) enabling students to identify (1) the specific problem solving task being addressed, (2) the level of progress at that point (specified as: not making progress, satisfactory, very good progress), and (3) whether the task is being done as a team or individually. The PDAs prompted students every 10 minutes, at which point each student recorded the task, his/her progress and whether it was done by and individual or the team. Figure 1 provides an example of one student’s problem solving pattern.

In Figure 1, the vertical axis shows the general problem solving task where non-productive tasks are shown below the horizontal timeline to indicate no progress towards problem solving. Triangles denote that the team is working on the task together; and the squares indicate individual task work. The larger the triangle or square, the more engaged the student(s) is (are) and progressing for that particular task (and the project, in general).

PDAs have allowed us to capture not only the problem solving steps for each team member, but also the combined process followed by the team. Figure 2 shows a summary of different team problem solving patterns gleaned from our PDA data. As shown, tasks can be divided up among individuals or solved by the full team. The team may work on each problem solving task sequentially or iterate among them; and devote a disproportionate amount of time to a particular task (e.g., problem formulation or implementation), or divide its time equally among tasks.

Figure 3 gives an example of PDA results for each member of a single team. As noted, the triangle indicates that the team was working together while the square indicates that the team member was working individually. Figure 3 suggests that students two and three were working closely together for over three hours (time steps are every 10 minutes), although for much of this time very little progress occurred, including the first hour which was devoted to problem formulation. Further, student one appears to have only participated for this first hour period and then dropped out, leaving his two partners to complete the assignment.

B. Data Collection

A sample of 47 sophomore industrial engineering students were asked to record their problem solving process while working on an MEA. One student’s data were not recognizable, leaving us with a sample of 46. Of these, 22 (or approximately 50%) were assigned the Tire Reliability MEA and the rest were assigned the CNC Machine MEA (please visit www.modelsandmodeling.net for descriptions and copies of these exercises).

The Tire Reliability MEA scenario is presented with an engineering memo and a large data set where a request is made to determine whether data collected from different batches of tires indicates that they are reliable. Students are provided with a “gold standard” data set and then asked to determine whether the data set they received can be considered reliable. They are therefore encouraged to think about engineering concepts like reliability statistics, and other issues such as ethical concerns. In solving the problem, students mostly used probability plots or goodness of fit tests. In the CNC Machine MEA, students find themselves in the role of an engineer who is given a request to determine whether investing in a new CNC machine is justifiable, based on data , including production time for the current CNC machine the firm owns and the candidate machine, as well as costs. Students are asked to determine whether and why the investment might or might not be beneficial to the firm. In solving this problem, students mostly used hypothesis testing, ANOVA or engineering economics methods.

Both MEAs were class assignments in an Engineering Probability and Statistics course; and students solved the problems and used the PDAs as an out-of-class assignment. The problems were solved by teams of two or three students.

C. Operationalization of Variables

The dependent variable of our analysis was the students' grade for the MEAs (artifact). Each MEA involved an individual and a group part. Individual questions were answered by each student, and the group questions were
handled by the group. The scoring was done by a trained, independent research assistant.

Independent variables were the process factors as given in Figure 2. The PDA problem solving process analysis has been done using three factors:

![Fig. 2 MEA Solution Approaches.](image)

**Analysis of Teamwork Process:** The first analysis was conducted to observe the impact of teamwork on the problem solving artifact. We categorized every student’s process based on whether all the members in the group were working on the same task (teamwork), whether a part of the group, such as two people were working on the same task (group work), or if they all worked on different tasks (individual work).

**Analysis of Iteration:** Next, we analyzed whether the students performed tasks in a linear manner (linear process); in other words, one activity at a time, or by revisiting some tasks multiple times (iterative process).

**Analysis of Emphasis on Tasks:** The third and last analysis was conducted on which phase of the problem solving process the students allocated the majority of their time. We grouped the students into four possible tracks: individuals that (1) spend a large portion of their time understanding or formulating the problem, (2) focus largely on the ‘intermediaries’- spend most of their time on figuring out model implementation, as opposed to modeling or interpreting the results etc., (3) allocate more time to interpreting the results, documenting the findings, and (4) allocate similar time to all the three of the phases.

**IV. ANALYSIS**

An analysis of the student process data obtained from MEAs has shown that out of the 46 students, 16 were individual problem solvers (approximately 35%), 6 were team problem solvers (13%) and 24 were group problem solvers (52%). Five students were iterative (11%) and 41 were linear (89%), showing that a majority of the students do not revisit tasks multiple times. Finally, nine students (20%) spent the most time at the beginning of the process, working on identification of the problem, eleven students (24%) spent the most time allocating about equal time to all phases, and the rest (56%) allocated the most time to finishing tasks like writing the student report. The average grade was 97 (stdev=20.3, range=56-135).

We tested the significance of factors by setting group grade as the response variable and the levels of three factors as independent variables. As control variables, we also included the grade of the individually completed section of the MEA, and the student’s gender. A high $R^2$ of 0.8 was obtained. Of the factors, we found that the individual grade was a significant predictor of the group grade ($p$-value<0.05). This result is expected given the majority of the students work in groups or work individually, as opposed to working in true teams. We found that students who worked in teams compared to group or individual problem solvers, obtained significantly better grades. The group solvers, on average, obtained eight less points than the team problem solvers ($p$-value=0.01), and the individual solvers received an average of 20 points less compared to the team problem solvers ($p$-value=0.001). Working iteratively or in a linear fashion was not observed to have a great effect on the grade, most likely due to the small number of people working iteratively, but majority of students did work in a sequential talk solving manner. Finally, in terms of the emphasis on phases, we observed that balanced workers, as opposed to students who put more emphasis on the beginning or the end phased earned 17 points more on average ($p$-value =0.05).

Differences between male and female students were also tested but no distinct patterns were observed. This result is more likely to relate to the fact that students are working in mixed teams where gender effects are mitigated.

**V. IMPLEMENTATION AND CONCLUSIONS**

This study provides an example of how handheld technologies; in particular PDAs can be used as a process assessment tool, providing insight into problem solving characteristics of students. Due to the availability of UMT software, the data for this study was collected and analyzed...
through the use of PDAs, but today, researchers can extend the findings of this study to smart phone technologies. As smart phones become increasingly more available, educational and commercial institutions might find it beneficial to develop similar software for use in smart phones. Since students are already well trained in using such tools and often own one, it might be cost effective and practical to switch from PDAs to smart phones, if possible.

In our analysis, we showed that by using PDA recorded data, one can observe the problem solving process that engineering students employ during a learning exercise. We are not suggesting that the results of this study can be generalized to all engineering students, but rather we are providing an example for other researchers on the use of PDA data to analyze process characteristics and process outcome.

In our learning environment, we have found that students who worked in teams and allocated time to each phase of the problem earned better grades compared to students who did not. We should note that the observation of a student allocating equal times to each phase is likely an indicator of no task delegation within the team; and this, once again, is a supportive finding to teamwork being instrumental in better problem solving outcomes. Using the analysis, an instructor would first notice that most students do not work in teams; and the students who do, earn better grades. Based on this information, students can be motivated to work in teams. In-class activities might be one way to achieve actual teamwork, rather than group work. Similarly, instructors can try to assign homework in parts, where students are encouraged to work on problem solving phases using similar time allocations, or revisit some parts of the problem repeatedly.

All in all, mobile technologies are beneficial in classrooms to measure, record, and evaluate educational activities, providing novel insights for the instructor about the teamwork characteristics and problem solving processes that students use. We expect and hope that new avenues of research and better instructional practices will arise as handheld devices become more common in engineering education environments.

REFERENCES


Tuba Pinar Yildirim received her B.S. in industrial engineering at Middle East Technical University in Ankara, Turkey (2004) and her M.S. in industrial engineering at University of Pittsburgh, Pittsburgh, PA, USA (2006).

She interned and worked as a system design analyst at firms including Robert Bosch, Renault S.A. and Fiat. Her publications appeared in Journal of Engineering Education, International Journal of Engineering Education as well as Journal of Marketing. She is currently a doctoral candidate and a pre-doctoral fellow at University of Pittsburgh, Industrial Engineering Department and Katz Graduate School of Business.

Ms. Yildirim is a member of IIE, Informa and AMA. She received the Best Paper in Engineering Education award in 2007 from Institute of Industrial Engineers.

Mary Besterfield-Sacre received the B.S. degree in engineering management from the University of Missouri-Rolla, the M.S. degree in industrial engineering from Purdue University, West Lafayette, IN, and the Ph.D. degree in industrial engineering from the University of Pittsburgh, Pittsburgh, PA.

She is an Associate Professor in the Industrial Engineering Department at the University of Pittsburgh. Her principal research interests are in empirical modeling applications and in engineering education evaluation methodologies. Prior to joining the Faculty at the University of Pittsburgh, she was an Assistant Professor at the University of Texas-EI Paso. She has worked as an Industrial Engineer with ALCOA and with the U.S. Army Human Engineering Laboratory. Dr. Besterfield-Sacre has been principal or co-principal by the investigator on over 20 sponsored research projects funded primarily National Science Foundation, U.S. Department of Education, and Engineering Information Foundation. Dr. Besterfield-Sacre is a former associate editor for the Journal of Engineering Education and co-author of the book Total Quality Management, 3rd Edition (Prentice Hall).

Larry J. Shuman (M’95) received his B.S.E.E. degree from the University of Cincinnati, Cincinnati, OH, and his Ph.D. degree in operations research from Johns Hopkins University, Baltimore, MD.

He is Senior Associate Dean for Academic Affairs, Swanson School of Engineering, University of Pittsburgh, Pittsburgh, PA, and Professor of industrial engineering. His areas of interest are improving the engineering educational experience and the study of the ethical behavior of engineers.

Dr. Shuman is the founding editor of ASEE’s Advances in Engineering Education, and is a coauthor of Engineering Ethics: Balancing Cost Schedule and Risk—Lessons Learned from the Space Shuttle (Cambridge, U.K.: Cambridge Univ. Press, 1997). He has been Principle or Coprincipal Investigator on more than 20 sponsored research projects funded from such government agencies and foundations as the National Science Foundation, U.S. Departments of Education, Health and Human Services, and Transportation, Robert Wood Johnson Foundation, and Engineering Information Foundation.