Development of RFID-Based Real-Time Inventory Tracking as a Project Assessment Tool in a Problem-Based Laboratory Environment

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Abstract – Tracking the effectiveness of teaching materials in a problem-based structured laboratory is challenging due to the open structure; where, students routinely make use of laboratory time outside of scheduled lab hours without direct instructor supervision. Determining the best framework for a lab can be problematic as instructors are not immediately available to receive feedback from students. This lag in real-time transfer of knowledge ultimately hinders the ability of an instructor to assess the provided lab scaffolding for effectiveness. One post-fact method to determine the effectiveness and identify potential weaknesses of provided materials is tracking time-to-completion of a lab project in comparison to designed expectations. An item level tracking of available, reserved, and in-use materials and equipment can be used as a basis for this type of assessment. This paper will discuss the necessary scaffolding along with challenges with real-time tracking of lab equipment materials based on UHF RFID technology, ethical concerns with real-time tracking, and an exploratory normative laboratory project assessment design. The use of this system for assessment of student group planning and instructor intervention will also be discussed.

Keywords: Problem-based laboratory, Assessment, RFID

INTRODUCTION

The problem-based approach to encourage learning in a supportive and collaborative structure has been shown to have positive long-term outcomes.[Hmelo-Silver 3] Problem-based instructional strategies enhance learning by engaging students in authentic, "real world" tasks. This approach begins with a final deliverable presented to the students who must solve one or more problems that require specific content knowledge or skill sets. Potential support provided to assist in problem-based student learning, here define as scaffolding, include availability of facilitators who provide content knowledge on a just-in-time basis, providing curriculum materials and/or software, and reducing cognitive load by structuring complex tasks.[Edelson 1, Hmelo-Silver 2, Puntambekar 8]

Problem-based learning in the laboratory

The biomedical engineering laboratories at the Georgia Institute of Technology aim to apply, reinforce, and add depth to a student's previously learned content knowledge through hands-on experiences. These laboratory courses may be an ideal fit for a problem-based-learning approach, where learning can be driven by an ongoing, complex multi-disciplinary problem throughout the course. However, in a hands-on laboratory setting, this approach presents

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unique challenges from a course development standpoint. Developing a researcher-laboratory resource relationship to aid in the problem solving task is important in research laboratories [Newstetter 6] and is a prerequisite when using hands-on equipment and instruments in a student centered setting. Limitations in availability of equipment and instrument resources can also constrain an otherwise real-world setting. Furthermore, in the open-structured laboratory, where students routinely make use of time outside of normally scheduled class hours, facilitators are not directly available to assist students. Hence, providing the correct tools at the right time with the proper prerequisite training can be a course design challenge.

RFID Technology

As a technology, radio frequency identification (RFID) has been implemented in industry for improved planning, inventory management, asset utilization, point-of-sale demand tracking, and labor productivity. Promoted by the Department of Defense (DoD), RFID technology can be hailed as an enabling technology to "get the warfighter the right material, at the right place, at the right time, and in the right condition" [Jones and Chung 4]. Its widespread use due to a DoD mandate and adoption by industry (e.g. Wal-Mart) has reduced costs of RFID materials. This reduction in costs has allowed more users to adopt this technology. The start-up cost of implementing the current system was less than $2000 and requires no additional human resources.

This paper will describe the development of an inventory-tracking scheme at Georgia Tech that has the potential to provide scaffolding for a problem-based laboratory course which enables the assessment of student and material performance.

RFID Platform as Scaffolding

In each module of the mandatory laboratory courses, students are presented with a directed problem. As an applied course, they begin by organizing any previous knowledge on the problem, posing additional questions, and identifying areas where more information is needed. The goal in developing this RFID based platform was to create a process that allows students to know what resources are available in the laboratory, to show students how these resources can be used, and to assist students in determining how resources could be used to help solve their proposed problem. By cataloging what and for how long an item was used by a student team, this RFID platform provides a potential benefit to the course instructor by identifying those that might need additional oversight and mentoring.

Background of RFID

As a platform, RFID is well established in a variety of asset tracking applications ranging from livestock to library books. A RFID system consists of three components, an antenna or coil, a transceiver (reader), and a transponder (tag), which holds digital information on a microchip. The antenna emits radio signals to activate the tag in order to read and write data. Antennas are the conduits between the tag and the reader, which controls the system's data acquisition and communication. The communication frequencies used depend on the application and can range from less than 135 kHz to 2.45 GHz (Table 1), and are regulated by the FCC (47 CFR Part 15), which limits the frequencies and power of systems.

Table 1. RFID communication frequencies and read range for RFID systems in the United States.

	LF	*HL*	*UHF*
Frequency Range	<135 KHz	13.45 MHz	902-928 MHz
Read Range (m)	<0.5	< 1	2-5

Advantages of RFID over standard bar code labeling include rewritable tags with unique serial numbers, no line-of-sight requirements, and inclusion of product history within the tag code. This ultimately lowers man-power requirements for tracking product inventory. Additionally, RFID has the potential tracking inventory in real-time tracking at an item level resolution, which is a highly desired attribute in any resource collection system.

RFID system hardware / software

Material resources for laboratory modules are housed in a smart cabinet. Requirements for this smart cabinet include a dense tag read and the ability to read tags in all spaces within the cabinet, i.e. ~ 1 m from the antenna. An UHF reader was used to meet these two requirements. The RFID smart cabinet was housed within the laboratory and was accessible to students at all times. The RFID smart cabinet included a UHF RFID reader (Alien Technology, ALR-9900), which communicated directly with the departmental network, two circularly-polarized antennas (ALR-9611-CR) to read RFID tags regardless of the tag's orientation, and an access control electric lock (Security Door Controls, ML200SLD) as shown in figures 1 and 2. The reader contains input / output ports which were used to drive the electric lock, eliminating the need for additional equipment and relays.

Figure 1. RFID reader used for tag identification. This reader communicates via local area network (LAN) and includes input output ports that allow for control of automated access control.

Figure 2. RFID smart cabinet housed in the laboratory. Antennas are housed on the top and bottom of the cabinet as highlighted in green. The electric lock (left) is driven by the reader input / output ports and includes a magnetic reed switch (right) to activate only when the door is closed, both highlighted in red.

The reader has the capacity for two additional antennas for potential growth and onboard Ethernet connectivity, eliminating the need for additional hardware. Access control is achieved by preprogrammed tags that software can link to a student or administrator group. All access is accomplished via this Alien Technologies RFID based reader system.

A program was written in Java to communicate with the reader; it sends messages at every state change, i.e. when an item was added or removed. This Java program takes the messages received from the reader and parses that message to populate a database showing the available items in real-time. The database was hosted on the BME department's SQL server which met all requirements for the system.

Students and administrators may access the database via the Internet at www.bme.gatech.edu/rfid. This web application was written with PHP to make SQL calls which report current tag or user information. Administrators can assign available equipment and instruments to a particular project using this website (Figure 3). Students are able to view and reserve available items. The system creates a history or project log file for each team at the item level.

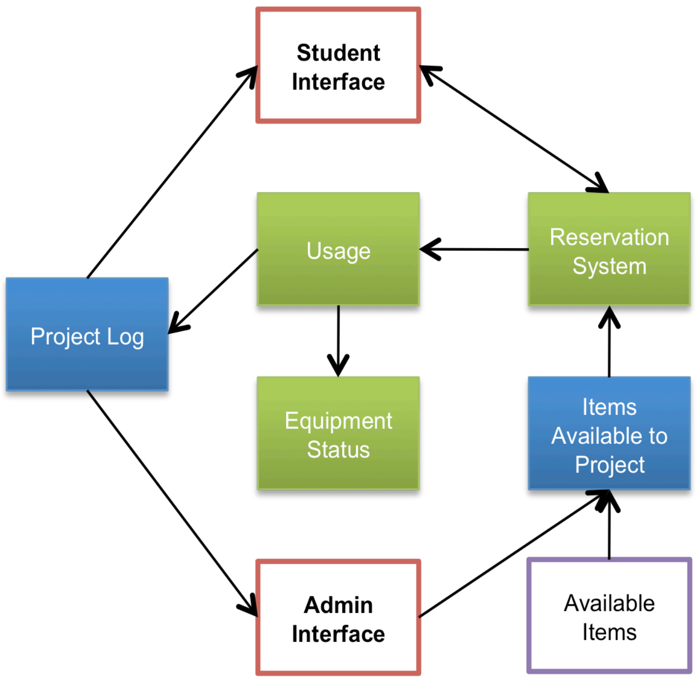

Figure 3. Representative schematic of RFID system database and developed software interface. The RFID reader provides real-time inventory of items (Available Items). Administrators manage availability based on project needs (Items Available to Project) and receive real-time reports of activities based on the project log. Students interface the reservation system and project log to see current activities.

The student interface is a simplified drag-and-drop checkout system, a recognizable format easing the transition of the system (Figure 4). This simple interface is linked within T-Square, Georgia Tech's implementation of Sakai, the open-source collaboration and courseware management platform (sakaiproject.org). A login screen takes students to the home page for respective teams, where team members can view their current inventory state.

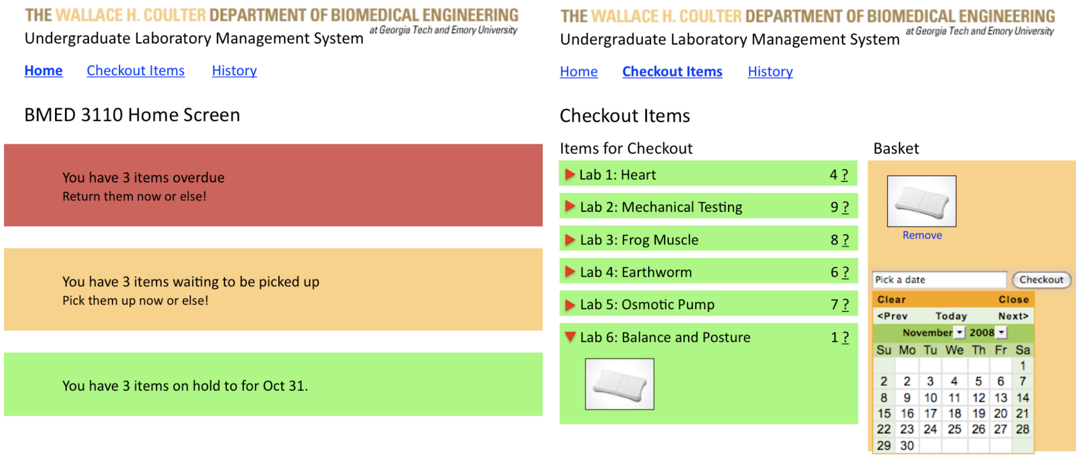

Figure 4. Home page (a) and checkout screen (b) for student interface. The homepage informs teams of historic and current resource usage. The checkout system provides a user-friendly method of inform students of available equipment and their potential use.

Because resources (instruments, equipment, etc.) are limited and must be shared between student teams, the system allows students to check out materials for a restricted time (currently 5 hrs). An automated email is sent to student teams if items have not been returned to the smart cabinet by the deadline. To reserve necessary equipment and instruments, students use the checkout screen. Each inventory item has an associated user guide article, either including the manufacturer's instructions or specifications for equipment and instruments.

Resource selection

All of the laboratory modules begin with an ill-structured [Hmelo-Silver 2] problem. In the Georgia Tech Biomedical Engineering hands-on laboratory courses equipment and instrument resource use is mandatory for problem solving. Constraining resources can limit an otherwise ill-structured problem ultimately limiting the open-ended nature of the lab module. Therefore, selection of resources, by itself, can be a learning opportunity that will prepare students for real-world problems. The RFID-based system, allows course designers to limit the selection of resources available to students, which constrains the problem to meet the objectives of the specific laboratory module. For example, in our balance and posture laboratory module with the objective of experimental design and data analysis resources are constrained to allow only for use of a force plate. In contrast, the mechanical testing lab with the objective of testing accuracy and precision of a measurement, the design of the screw-type testing device itself is open ended, which allows students to use many available resources such as different motors, drivers, bearings, slides, and many potential extensometry options.

For each module, course designers can limit the availability of resources from the administrator login of the RFID system. This allows course designers to vary the constraint of the lab module from a resource perspective. Instructors and teaching assistants can also examine a team's progress by their resource choice, providing guidance and mentoring when appropriate.

Leveraging RFID for Assessment

The laboratory course uses several assessment strategies as learning tools. A summative assessment strategy is used to document the quality of the deliverable for the laboratory, i.e. the proficiency of the student team in achieving the goals of the laboratory module, and a process assessment strategy is used to determine the degree of difference from a student's expected plan for the module including the final presented deliverable. The current RFID platform is designed to assist with the latter assessment strategy, evaluating the process, i.e. milestones that need to be met to achieve the specific deliverable of a laboratory module. Specifically, the system has the potential to identify teams where timely interventions might be appropriate to provide assistance with the module, assess the team's project management efficiency, and assess the provided scaffolding to ensure that expectations of student learning is justified.

Several project tracking and assessment tools were developed with the aid of RFID based real-time tracking. These included a methodology to assess a team's project management efficiency, identify groups where additional facilitation might be necessary, and assess the effectiveness of the module scaffolding by measuring time to completion.

Team Facilitation

Facilitating the teams that need additional mentoring is an important aspect of problem-based learning. The RFID-based system has the potential to identify some of these teams by using equipment and instrument resources and by examining the total time a team spent on the module. During the laboratory module problem design, an estimated minimum and maximum time was uploaded to the system (Figure 5). On a daily basis, the system looks at team use of resources. If the actual use of resources by a team is either below or above the time determined, the course instructor and teaching assistants are informed and provide added feedback and facilitate the team's progress.

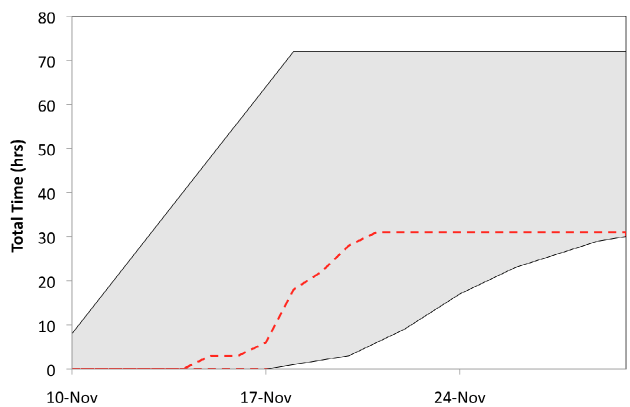

Figure 5. Estimated and representative time for project completion. The shaded area represents the minimum and maximum estimated time to complete the lab module, on a daily basis. The dashed red line represents a team that was able to complete the project within the expected time.

Project management

To approach the complex hands-on biomedical engineering problems assigned in the teaching laboratory student must first organize available information. Specifically, students must compile sufficient information to provide required performance characteristics of the resource with the goal of addressing the given problem and providing an estimated time to complete the project. By carefully defining and providing the deliverables and potential resources for the specific laboratory module, students can begin to address these first two tasks.

Teams interface with the system by determining their required materials via an online reservation system. Students are informed that the team reservation time is used as the estimated time for their team's project completion. This system ensures that the required materials are available for team use when an item is needed. Once equipment and materials are in the system, team members are granted access to the RFID cabinet. The system automatically tracks equipment usage and maintains a project log that includes both reserved time and actual use time. The efficiency of the team is calculated by comparing the actual resource use to this estimated time.

Once the deliverables are collected for summative assessment, instructors access this system to review an efficiency report for each team. This efficiency report can be used to provide feedback to students, show course wide statistics of estimated and actual time spent on hands-on work, which informs students of team efficiency allowing them to quantitatively evaluate their lab module planning and total time spent.

Scaffold evaluation

Designing the right type of scaffolding for problem in PBL can be an iterative process [Newstetter 5]. Ideally, student stumbling blocks can be anticipated and addressed with timely course scaffolding (e.g. direct instruction from a teaching assistant). Open course structures, where students are not in regular contact with instructors, make determining the needs of students promptly a challenge. This system has the potential to assess the effectiveness of the provided materials in achieving the desired objectives by examining the estimated total time for project completion. Two criteria can be used for assessing the provided materials: (1) a majority of students surpassing a total resource use time greater than the expected maximum time allotted for the lab module and (2) calculated difference between actual use and reserved time for resources. A formative assessment strategy could be used to better determine where deficiencies occur in the learning process and how to better structure the scaffolding and facilitation to address identified areas.

ETHICAL CONCERNS

RFID is one of the most invasive surveillance technologies threatening privacy. Issues include hidden item level tags, which allow for person profiling, and embedded tags, which allow for individual tracking (e.g. as used for clothing or currency).[Peslak 7] The high frequency tags (850–950 MHz) used in the Georgia Tech BME system have longer read ranges and are capable of item level triangulation. Creating a surveillance based assessment strategy is not the goal of this project and is potentially counterproductive when applied to problem-based learning, which strives to develop a student's knowledge base by engaging learners in the process. The benefits of the system (streamlined scheduling and assessment) must carefully be weighed against individual privacy concerns. It is also important to assess what student perception is of using an automated tracking system in a laboratory setting.

In the Georgia Tech Biomedical Engineering system, teams, not individuals, are directly tracked. The linkage between a team's RFID access card and member identification is controlled under the same standards as the student grading system. The provided reports of the system are not used for grading an individual student, but are used as a basis for further formative assessment.

CONCLUSIONS

An RFID-based system in a hands-on problem-based learning laboratory setting has benefits beyond simple inventory tracking. The provided reports of the system, which include examining a team's efficiency, determining when additional team facilitation might be necessary, and determining the effectiveness of the provided scaffolding may be used as a basis for further formative assessment. Systems can deliver and provide assessment of laboratory module scaffolding. By tracking at a team, not an individual level, and placing safeguards on information storage, the benefits of this RFID system outweigh potential ethical concerns.

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