Remote Administration and User Experience Evaluation of the iLab Heat Transfer Project Site

by

Rodney K. Graham

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Submitted to the Department of Electrical Engineering and Computer Science
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Abstract

The iLab Heat Transfer Project provides a means for students to remotely execute, via a web interface, experiments related to the topic of heat transfer. The website associated with this project provides instructors with the ability to remotely manage the performance of experiments by their students. This thesis describes improvements made to this website that are intended to grant more control to instructors. Specifically, the website has been augmented to provide remote instructors with complete control over experiment scheduling, user registration, document uploading, and other relevant administrative tasks. The interfaces by which users perform experiments have been modified to incorporate an audio and video feed of the laboratory equipment used in these experiments. In addition, the website has been extended with a feature that facilitates the viewing and analysis of questionnaire responses collected from students. The questionnaire responses provided by students have been examined to gain more knowledge about the effectiveness of various aspects of the website and experiment interfaces.

Thesis Supervisor: Clark K. Colton
Title: Professor of Chemical Engineering

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1 Introduction

1.1 Background

The iLab Heat Transfer Project was initiated in an effort to develop web-accessible laboratory experiments that would be useful in teaching principles of heat transfer. These web-accessible laboratory experiments can be useful when incorporated into courses that otherwise would not have a laboratory component. They also make it possible for students to gain some experience with laboratory equipment that might otherwise be inaccessible to them [2].

Students are able to experiment with laboratory equipment through a collection LabVIEW Virtual Instruments (VIs). These Virtual Instruments mirror the controls and sensors available on the actual equipment and allow students to exercise remotely the same control that a person directly interacting with the equipment would have. As of now, Virtual Instruments have been developed that provide students with the ability perform experiments dealing with heat exchange, conduction, convection and radiation processes.

The Virtual Instruments are accessible via a website at which individuals can register and schedule time for experimentation. The website also provides information regarding the operation of available equipment and instructions on performing experiments. Instructors who register their courses with the website are provided with additional permissions that allow them to perform some administrative tasks such as assigning their students to teams and specifying which times to make equipment available for use by their students.

1.2 Problem Statement

The preexisting website provided some basic features with which instructors (administrators) could manage students, manage experiment scheduling, and post announcements, however, many features needed to allow instructors complete administrative control were either missing or underdeveloped. This included, among other things, the ability to post and manage documents (e.g. assignments) on the website; the ability to automatically add content from a course session to an archive of past session content; the ability to fully edit student registration information and team assignments; and the ability to set which experiment is active.

Previously, performing these tasks required logging in to the machine that serves the website and editing the database and code that back the website. In addition to being an issue of convenience, this scheme requires that instructors have the necessary technical knowledge (i.e. database, ASP.NET, C# experience) to make the desired changes. More critically, this scheme requires that instructors have access to the server and that they are provided with an account on the machine. This is both impractical (expecting instructors to have the necessary technical background) and dangerous (having individuals outside the technical staff of the project make such modifications). One tested alternative, having the iLab Heat Transfer Project staff make changes that instructors could not make themselves, provides a less than optimal solution: time-zone differences, schedule conflicts, and other communication difficulties add unnecessary delays and prevent effective website use. As such, one of the objectives of this thesis was to establish a comprehensive set of tools that would allow instructors to perform the vast majority of administrative tasks via the iLab Heat Transfer Project website with minimal technical knowledge and minimal assistance from the project staff.

Another objective of this thesis was to examine students' opinions on their experience using the website and performing experiments. User experience surveys were conducted and the available data needed to be examined. To do this, it was necessary to take the data from the existing paper surveys and convert it to an electronic format that would allow statistical analysis. Subsequently, a means of displaying and analyzing this information had to be developed. The resulting system, in addition to facilitating the analysis of current survey data, can accommodate the entry, archiving, display and analysis of future survey data. The results yielded from examination of the survey data were used to author a paper on user opinion of the iLab Heat Transfer Project remote experiment interface.

1.3 Thesis Outline

Chapter 2 provides an overview of the iLab Heat Transfer Project. Specifically, it describes the state of the project before the improvements detailed in this thesis were implemented. This includes descriptions of the website, experiment interfaces, software backend, and laboratory equipment.

Chapter 3 describes the improvements and extensions made to the set of administrative features available on the iLab Heat Transfer Project website. It describes the addition of features that provide instructors (administrators) with the ability to manage documents, users, experiments, and other information related to their courses. Improvements to the facilities for posting announcements and archiving course content are also detailed.

Chapter 4 covers the work done concerning student questionnaire data that pertains to the usefulness and effectiveness of the iLab Heat Transfer Project website and experiment interfaces. The redesign of the underlying questionnaire framework is explored as is the website interface created for viewing and analyzing questionnaire data. A summary of the results gathered from analysis of the questionnaire data is also provided.

Chapter 5 discusses the remaining improvements made to the iLab Heat Transfer Project website and experiment interfaces. This includes a discussion of the integration of a camera feed into experiment interfaces and a discussion of the modifications made to experiment Virtual Instruments.

Chapter 6 provides concluding remarks and presents recommendations for future work for the iLab Heat Transfer Project.

2 Overview

2.1 Website

The website for the iLab Heat Transfer Project, located at the address http://heatex.mit.edu/HeatexWeb at the beginning of the work of this thesis, provides users with information about the project as well as the ability to register and access any currently active experiment. Users visiting the site are presented with a front page that displays the title of the active experiment as well as any recent announcement posted by instructors (see Figure 2-1). Located on the left of the front page, and all pages of the site, is a navigation panel that assists individuals in using the site. The navigation panel, visible in Figure 2-1 [3], is divided into three sections: Access, Website, and Experiments. The Access section of the navigation panel provides links related to accessing the site and experiment (e.g. site registration, scheduling of experiment time). The Website section presents links to information about the project, including relevant publications and an archive of content from courses that have used the website. The Experiments section provides links to information about the laboratory equipment and experiment instructions. This section also presents a link to the page that provides users with access to the interface page for the current active experiment.

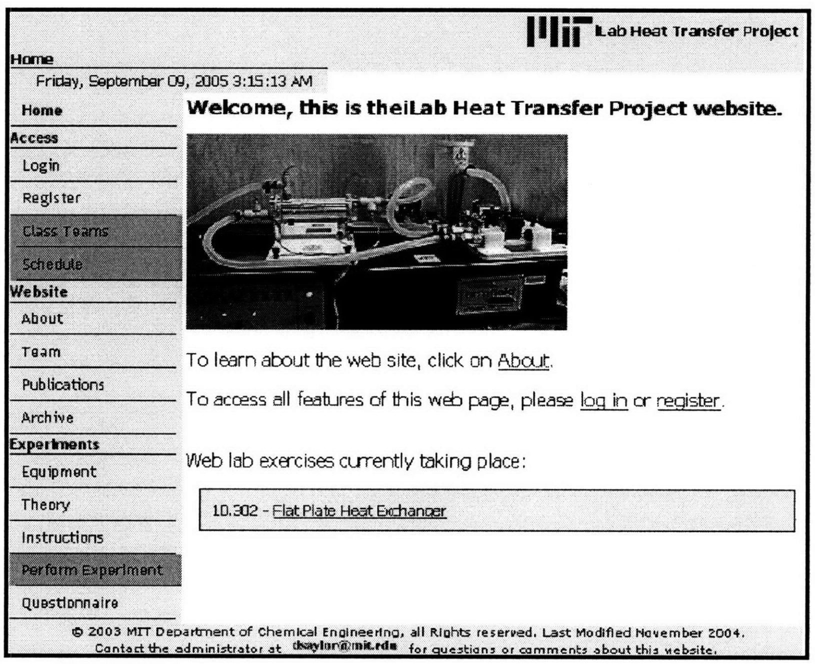


Figure 2-1: Front page of the iLab Heat Transfer Project website (previously located at http://heatex.mit.edu/HeatexWeb).

Users visiting the site, who have not yet logged in, will notice that certain links on the navigation panel, such as the link providing access to experiment interface pages, are grayed out. Upon logging in to the site, these links are made available to users. Furthermore, there exists another hidden section of the navigation panel that is only accessible to users, logged in to the site, who have administrative privileges (e.g.

instructors). The Admin Functions section, as it is labeled, contains links to features that allow instructors to perform administrative tasks. At the outset of this thesis, this included viewing basic information (e.g. full name, username) for registered students; managing the timeslots available to perform experiments; posting announcements; and registering (a batch of) students for the site.

The machine that serves the pages of the website (heatex.mit.edu) is located in a laboratory facility in the subbasement of building 66 (66-0039). The machine, which has the operating system Microsoft Windows 2000 Server Advanced installed, uses the Microsoft Internet Information Services (IIS) web server. At the outset of the work for this thesis, the website was still in the process of migrating content from static HTML pages to ASP.NET pages. Microsoft Visual Studio .NET has been used in the design of the new (ASP.NET) pages. The machine also runs Microsoft SQL Server 2000 to provide the database backend for storing and accessing site data (e.g. user registration information).

2.2 Experiment Interface Pages

In order to perform an experiment, users must access the interface page for that experiment. The "Perform Experiment" section of the website provides users with a link to the interface page for the currently active experiment. Each of the seven existing experiments (i.e. LabVIEW Virtual Instruments) has an associated experiment interface page. All of the pages are identical in content and, at the start of this thesis, included just a chat facility and a LabVIEW Virtual Instrument. An audio and video feed of the laboratory equipment being used for experimentation is also published over the web. The feed previously was only accessible by use of a stand-alone video player; the VLC media player, because of its availability on multiple platforms, was the recommended player.

2.2.1 Chat Facility

Located at the top of experiment interface pages (see Figure 2-2) is a chat facility intended to allow communication between users who are performing an experiment as a group. Users must first login via the chat facility, using the same username/password combination used for the website, before beginning a chat. The Java chat applet displayed on the experiment interface page passes user messages to a Java chat server application running on the iLab Heat Transfer Project server that manages the relaying of messages between the chat applets of different users.

For users collaborating via the web on an experiment, the chat facility allows them, among other things, to coordinate passage of control of the experiment interface between themselves. In addition, it allows users to communicate with an instructor who may be available, in the laboratory facility, to address any concerns or problems that arise during experimentation.

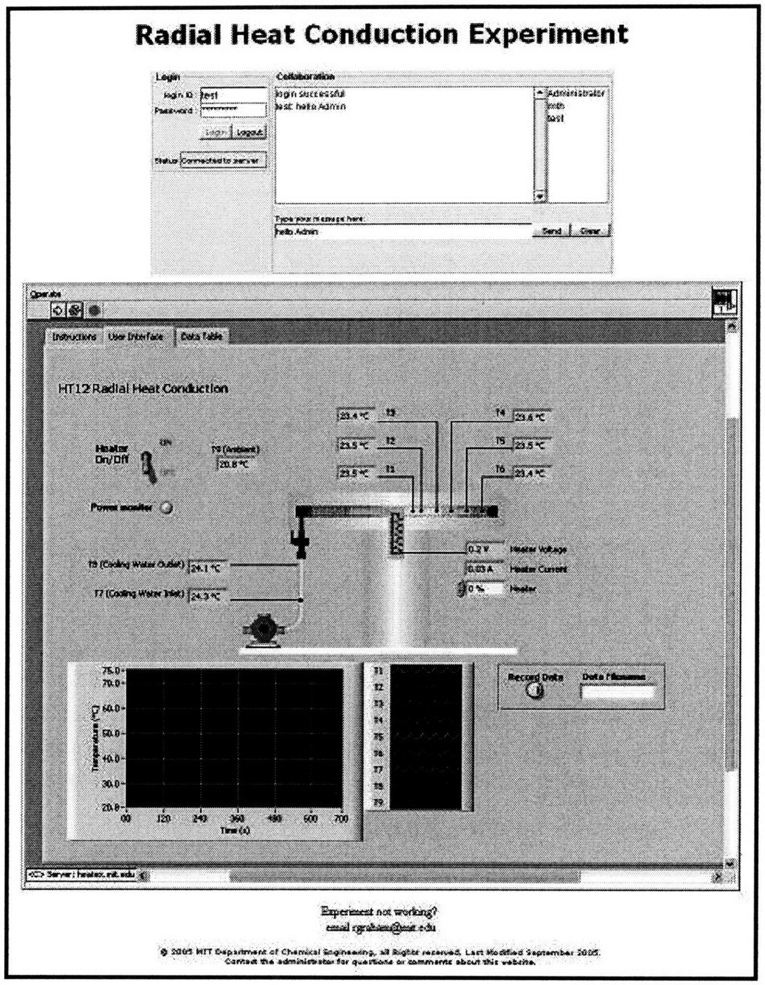


Figure 2-2: Experiment interface page for the Radial Heat Conduction Experiment.

2.2.2 Audio/Video Feed

In order to address the "black box" feeling that may be elicited by remote experimentation via the web, a camera is setup in the laboratory to transmit an audio and video feed. The camera is positioned to relay footage of the laboratory equipment being used with the current experiment. This allows users to get some of the visual and auditory feedback that would be available to them if they were performing the experiment in the actual laboratory facility housing the equipment.

Before any site improvements were made, this web camera feed was available at the address http://heatex.mit.edu:8080. Users could view the feed with any compatible media player of their choosing. Due to its versatility, the recommended player was the VLC media player [3].

2.2.3 Virtual Instruments

A Virtual Instrument (VI) (see Figure 2-4) presents users with the interface that allows them to actually interact with laboratory equipment. A VI provides users with all the control inputs and sensor outputs necessary to carry out experimentation. Changes that users make via the VI controls are transmitted to the corresponding laboratory equipment and the values of any sensors on the equipments a sent back to the VI. This cycle happens continuously allowing users to interact with laboratory equipment in real-time.

The experiment VIs for the iLab Heat Transfer Project, of which seven exist, were created using the programming language LabVIEW (designed by National Instruments). The server located in the laboratory facility, which serves the pages of the website, also runs a separate LabVIEW web server that is responsible for serving the VIs. To view a VI, a user must install the appropriate LabVIEW web browser plugin that corresponds to the version of the LabVIEW server (version 7.0).

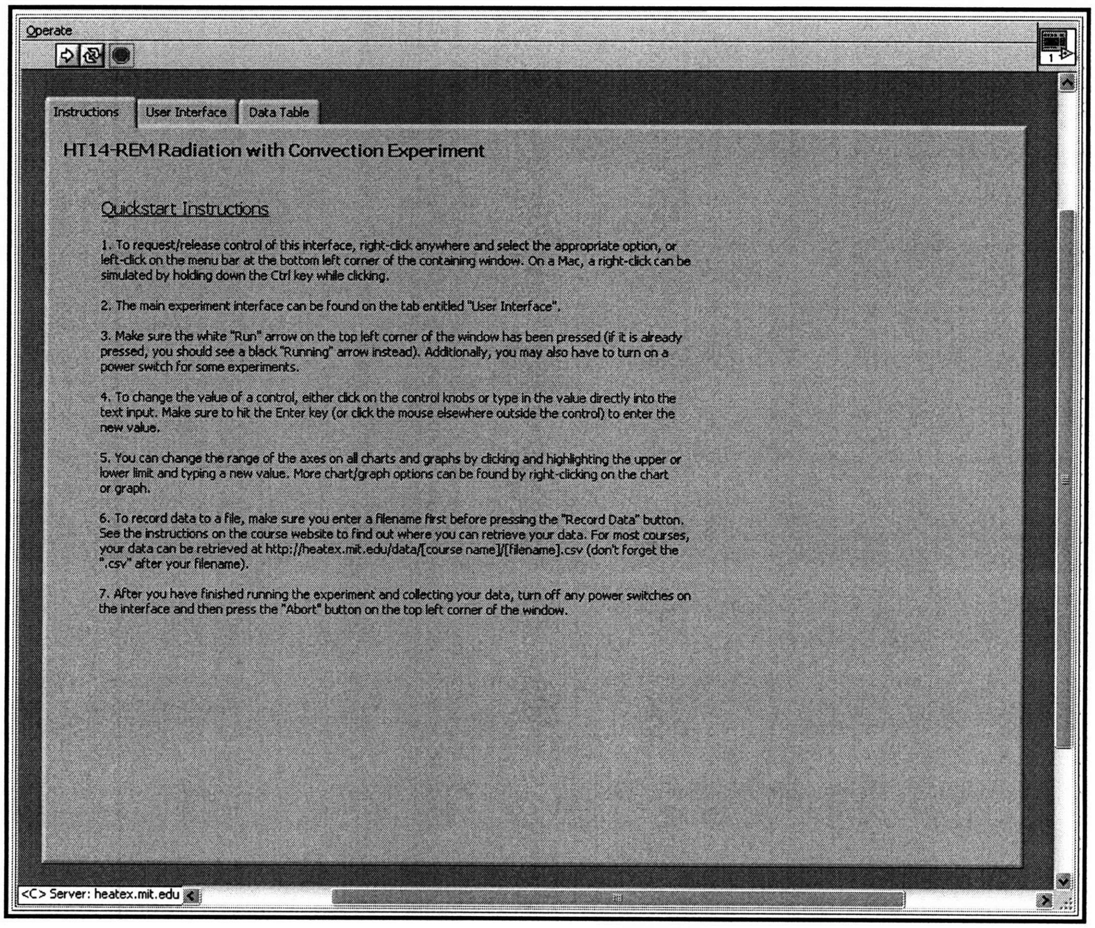


Figure 2-3: Virtual Instrument for Radiation with Convection Experiment with Instructions tab selected.

While the details of the content of the VIs vary, they all present users with a basic three-tab structure: Instructions, User Interface, and Data Table. The Instructions tab, pictured in Figure 2-3, shows a set of general instructions for interacting with the VI. The User Interface tab, pictured in Figure 2-4, provides the main experiment interface through which a user interacts with lab equipment and gathers data. Finally, the Data Table tab, pictured in Figure 2-5, presents a table containing the most recent sensor/parameter recordings. By default, the table displays the last 30 sets of sensor/parameter snapshots, however this value can be increased or decreased by way of the control at the bottom of the panel. Aside from these three tabs, some VI panels also have hidden tabs that can only be accessed from the server console. The hidden tabs provide administrators with the ability to control addition aspects of the experiment.

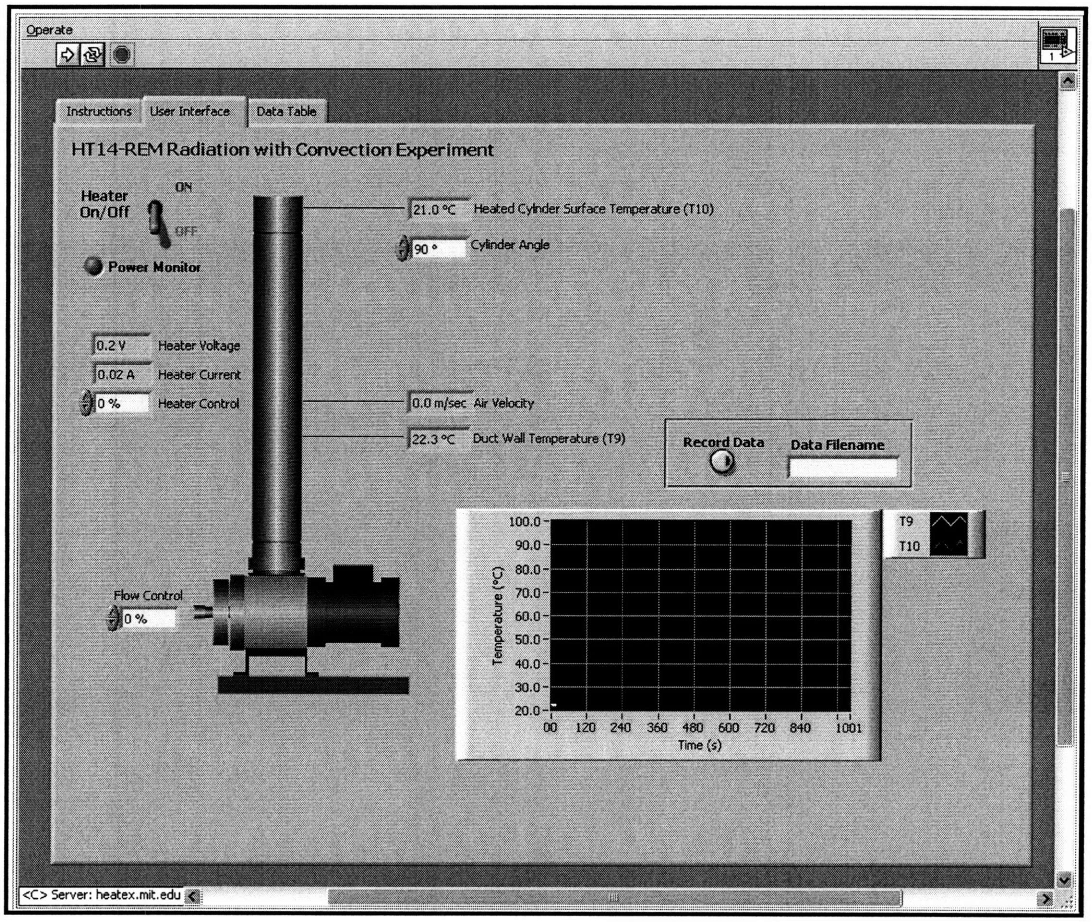
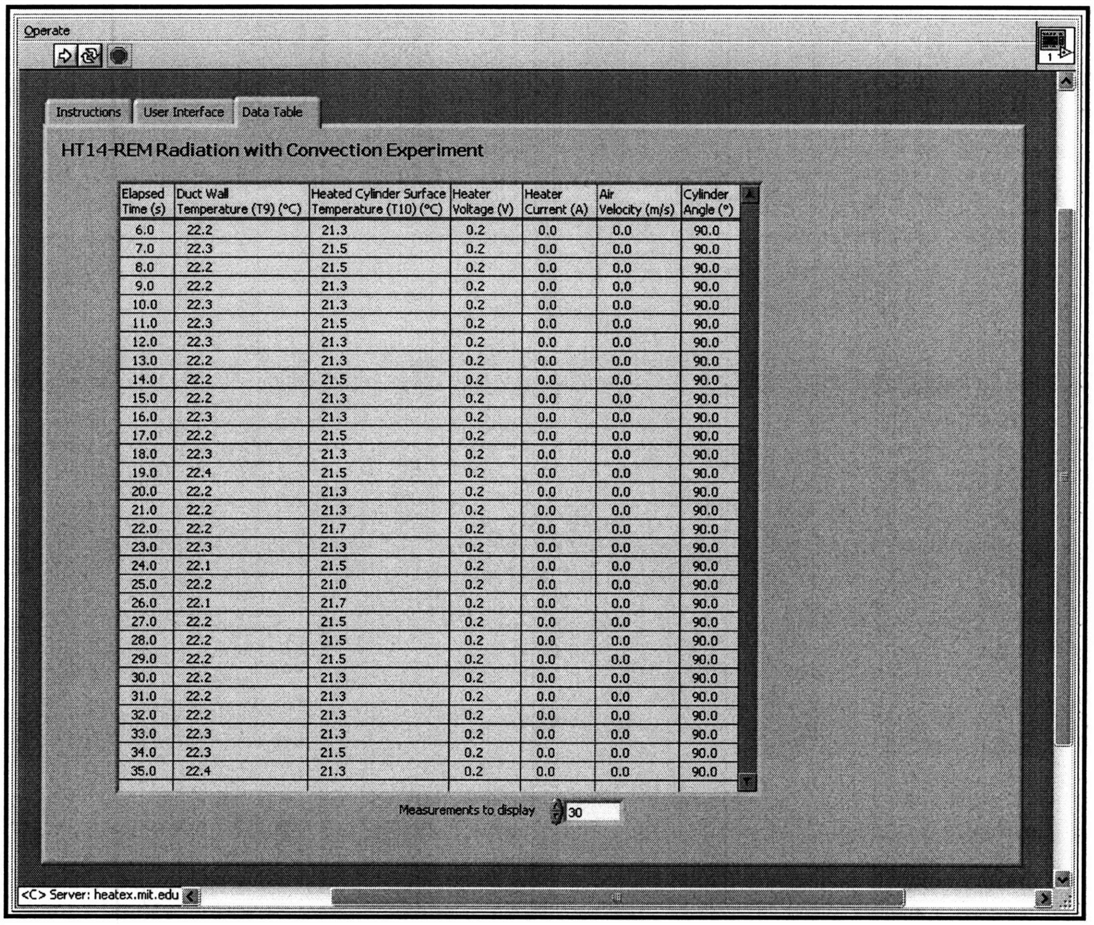


Figure 2-4: Virtual Instrument for Radiation with Convection Experiment with User Interface tab selected.



Elapsed Time (s)	Duct Wall Temperature (T9) (°C)	Heated Cylinder Surface Temperature (T10) (°C)	Heater Voltage (V)	Heater Current (A)	Air Velocity (m/s)	Cylinder Angle (°)
6.0	22.2	21.3	0.2	0.0	0.0	90.0
7.0	22.3	21.5	0.2	0.0	0.0	90.0
8.0	22.2	21.5	0.2	0.0	0.0	90.0
9.0	22.2	21.3	0.2	0.0	0.0	90.0
10.0	22.3	21.3	0.2	0.0	0.0	90.0
11.0	22.3	21.5	0.2	0.0	0.0	90.0
12.0	22.3	21.3	0.2	0.0	0.0	90.0
13.0	22.2	21.3	0.2	0.0	0.0	90.0
14.0	22.2	21.5	0.2	0.0	0.0	90.0
15.0	22.2	21.3	0.2	0.0	0.0	90.0
16.0	22.3	21.3	0.2	0.0	0.0	90.0
17.0	22.2	21.5	0.2	0.0	0.0	90.0
18.0	22.3	21.3	0.2	0.0	0.0	90.0
19.0	22.4	21.5	0.2	0.0	0.0	90.0
20.0	22.2	21.3	0.2	0.0	0.0	90.0
21.0	22.2	21.3	0.2	0.0	0.0	90.0
22.0	22.2	21.7	0.2	0.0	0.0	90.0
23.0	22.3	21.3	0.2	0.0	0.0	90.0
24.0	22.1	21.5	0.2	0.0	0.0	90.0
25.0	22.2	21.0	0.2	0.0	0.0	90.0
26.0	22.1	21.7	0.2	0.0	0.0	90.0
27.0	22.2	21.5	0.2	0.0	0.0	90.0
28.0	22.2	21.5	0.2	0.0	0.0	90.0
29.0	22.2	21.5	0.2	0.0	0.0	90.0
30.0	22.2	21.3	0.2	0.0	0.0	90.0
31.0	22.2	21.3	0.2	0.0	0.0	90.0
32.0	22.2	21.3	0.2	0.0	0.0	90.0
33.0	22.3	21.3	0.2	0.0	0.0	90.0
34.0	22.3	21.5	0.2	0.0	0.0	90.0
35.0	22.4	21.3	0.2	0.0	0.0	90.0

Figure 2-5: Virtual Instrument for Radiation with Convection Experiment with Data Table tab selected.

2.3 Laboratory Equipment

The experiments developed for the iLab Heat Transfer Project make use of laboratory equipment manufactured by Armfield Ltd. As the title of the project suggests, all equipment is related to the study of heat transfer processes. More specifically, equipment is used either in the study of (1) heat exchanger processes or (2) heat conduction, convection and radiation processes. There exist two service units, the HT30XC and the HT10XC, shown in Figure 2-6 [2], which supply the base infrastructure for interfacing with a computer (via USB). In addition to this, there is smaller accessory equipment that can be used for specific experiments. As illustrated by Figure 2-6, the HT30XC service unit is used for experiments involving heat exchange accessory equipment, while the HT10XC service unit is used for experiments involving heat radiation, convection or conduction accessory equipment. Various sensors (e.g. thermocouples) located on the accessory equipment connect to sensor ports of the service units; this allows transmission of sensor data to the server and to a LabVIEW Virtual Instrument running on the server. Similarly, the service units allow users, by way of a VI, to specify the settings of certain equipment controls. Experiment Virtual

Instruments exist for all accessory units with the exception of the HT31 tubular heat exchanger accessory.

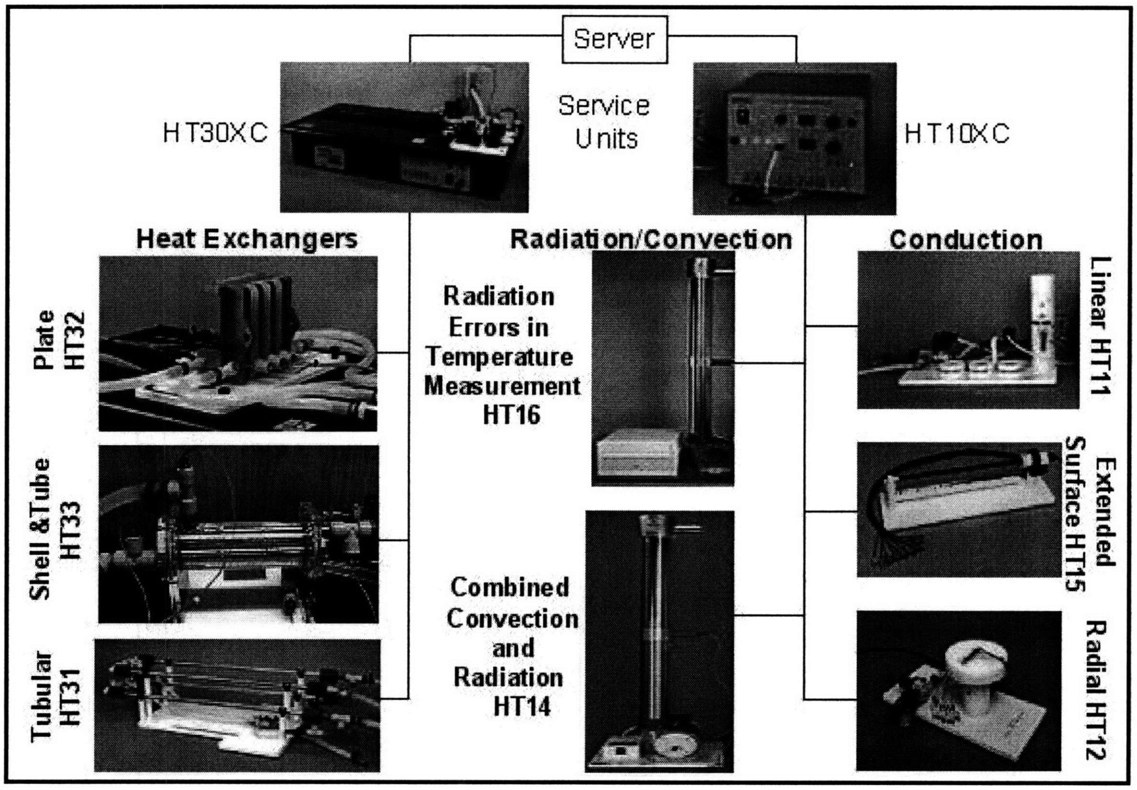


Figure 2-6: Heat transfer laboratory equipment used by the iLab Heat Transfer Project.

2.4 Questionnaires

After a course has finished performing an experiment, it has been custom to gather student feedback about their experiences using the site. An online questionnaire was developed to facilitate the collection of this information. The precise content and design of the questionnaire has changed from year to year and, to a lesser extent, from experiment to experiment, however in all forms the questionnaire presents responders with a collection of statements and asks them to rate how strongly they agree with each statement on a scale of 1 (strongly disagree) to 7 (strongly agree). Statements address a variety of topics ranging from the usability of the experiment interface pages to the ability of the experiment to illustrate heat transfer concepts.

The previously used scheme for storing questionnaire data required the creation of a new database table for each questionnaire. The questionnaire database tables were structured such that they contained a column for each question on the corresponding questionnaire (with a nominal title of the format Q1, Q2, etc.); the tables also contained columns to record user identifying information such as the user ID (see Section 3.3), full name, and course of the responder. Each row in the questionnaire tables corresponded to a student and his questionnaire responses, where the value of each questionnaire item column was the response of the student to the corresponding questionnaire item.

In addition to storage in a database table, for each responder to a questionnaire, an HTML version of the questionnaire form filled with his responses was saved. Given that responses were stored in database tables without any reference to the actual content (text) of the questions that elicited them, the examination of questionnaire responses from past years was problematic. This feature was implemented with the intent of addressing the issue [3].

1. Team Profile

	1 = Strongly Disagree, 7 = Strongly Agree
a. My team worked well together.	○1 ○2 ○3 ○4 ○5 ○6 ○7
b. Everyone on my team contributed in a meaningful way.	○1 ○2 ○3 ○4 ○5 ○6 ○7
c. My team was motivated.	○1 ○2 ○3 ○4 ○5 ○6 ○7
d. When collecting data, I prefer to work in a team rather than alone.	○1 ○2 ○3 ○4 ○5 ○6 ○7
e. When analyzing data, I prefer to work in a team rather than alone.	○1 ○2 ○3 ○4 ○5 ○6 ○7

2. Running the Experiment

Usability when carrying out the experiment.	1 = Strongly Disagree, 7 = Strongly Agree
a. The instructions were clear.	○1 ○2 ○3 ○4 ○5 ○6 ○7
b. I had no problems operating the experiment.	○1 ○2 ○3 ○4 ○5 ○6 ○7
c. I was able to make transient and steady state temperatures as required.	○1 ○2 ○3 ○4 ○5 ○6 ○7
d. I was able to record and retrieve the data needed for the assignment.	○1 ○2 ○3 ○4 ○5 ○6 ○7

Figure 2-7: Excerpt from online questionnaire form.

3 Administrative Tools

Detailed in this chapter are the improvements of existing administrator website features and the addition of new administrator website features. Administrator features of the website are accessible only to those users with administrative privileges; these privileges are only granted to course instructors (and teaching assistants) and project staff. Given this and the fact that the features to be discussed below are meant to be used primarily by instructors (and their teaching assistants), the term "instructor" will often be used in this chapter in place of the term "administrator" (i.e. a user with administrative privileges). However, it should be noted that these features are available to any user of the site that has been granted administrative privileges.

3.1 Document Management

During the course of using the iLab Heat Transfer Project site, it is usually necessary for instructors to post documents, such as assignments, to the site. Additionally, project staff members often need to add manuals and research publications to the site. The prior version of the website presented no quick, simple means by which this could be done. Previously, adding a file to the site required (after copying the file to the server) editing the HTML of the appropriate page of the site to add a link to the file. This scheme requires instructors to (1) have appropriate access to edit the code of the web pages residing on the server and to (2) have the technical knowledge (of HTML, at least, and possibly also ASP.NET and C#) necessary to make the changes to the code of the website to post a link to the new file.

The previously used solutions to these issues were (1) providing instructors with access to the server via a VNC server application running on the machine so they could make the changes themselves and (2) having someone on the iLab Heat Transfer Project staff make the required updates for instructors. While the former solution provided instructors with the server access necessary for editing the website, it still required that instructors have technical knowledge that might not be reasonable to expect them to have. Moreover, ignoring this issue, providing every instructor using the iLab Heat Transfer Project site with direct access to the main server unnecessarily increases the probability of someone accidentally trashing something on the server. Alternatively, the second solution, while addressing the matter of technical knowledge and limiting the amount of people with access to the server, introduced an intermediate step to the use of the site by instructors that led to inefficiency. Ideally, instructors working with the project should be able to conduct routine tasks with minimal assistance from project staff members.

As part of the work of this thesis, an interface has been added to the website that allows instructors to post new documents (i.e. files) to the website and manage those documents once posted to the website. As pictured in Figure 3-1, the document management interface contains two sections that pertain to (1) posting a new document to the website and (2) managing documents already posted to the site.

3.1.1 Addition of a New Document

To post a document to the website, an administrator first specifies the location of the document file in the "Document Location" field. By pressing the "Browse..." button located next this field, a file dialog window is presented that assists in determining the location of the document file.

After specifying the location of the document file, the type of the document must be indicated by selecting a document category from among the options available under the heading "Document Category": admin manual, assignment, publication, questionnaire, and theory. The categories correspond to sections of the site and determine where a link to the new document will be added.

The "Document Title" field allows the specification of the title to be associated with the new document. The use of the information entered in this field varies by document category. For nearly all of the document categories, the title entered here will be used for the text of the link to the document. However, for documents added with the category "publication," the title information is used as the reference information for the document. Figure 3-2 shows the Publications section of the website where each document is listed with its reference information. Notice that the format extension of the document serves as the link to the actual document in this case.

The final two fields, "Course" and "Session", indicate the course and session with which the document is to be associated (e.g. 10.302 and Fall 2005). This information does not affect where or how a document is posted, but is used during the archival process. (See Section 3.2 for a detailed examination of the archival process and the concept of sessions.)

Finally, the "Upload File" button is pressed to upload the document with the specified parameters. If all the entered information passes validation, the document is uploaded and the user is presented with a confirmation message; otherwise, the user is asked to correct the supplied information.

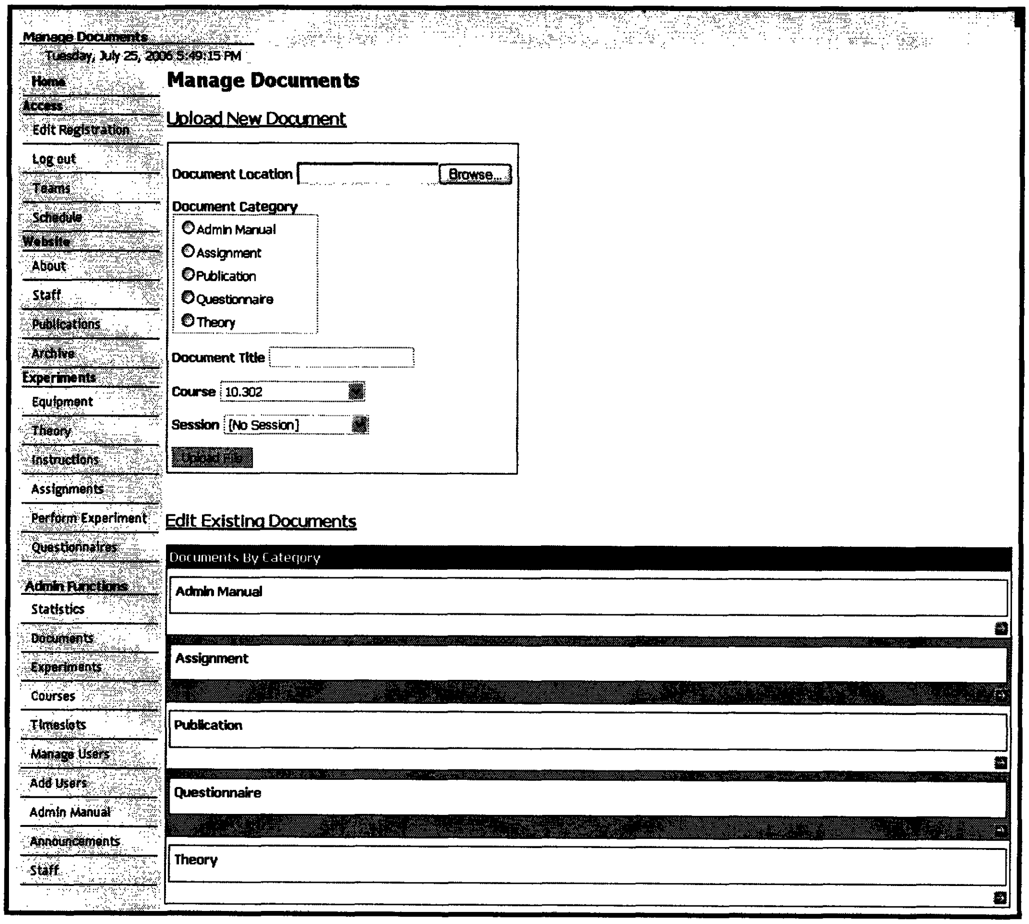


Figure 3-1: Document management interface.

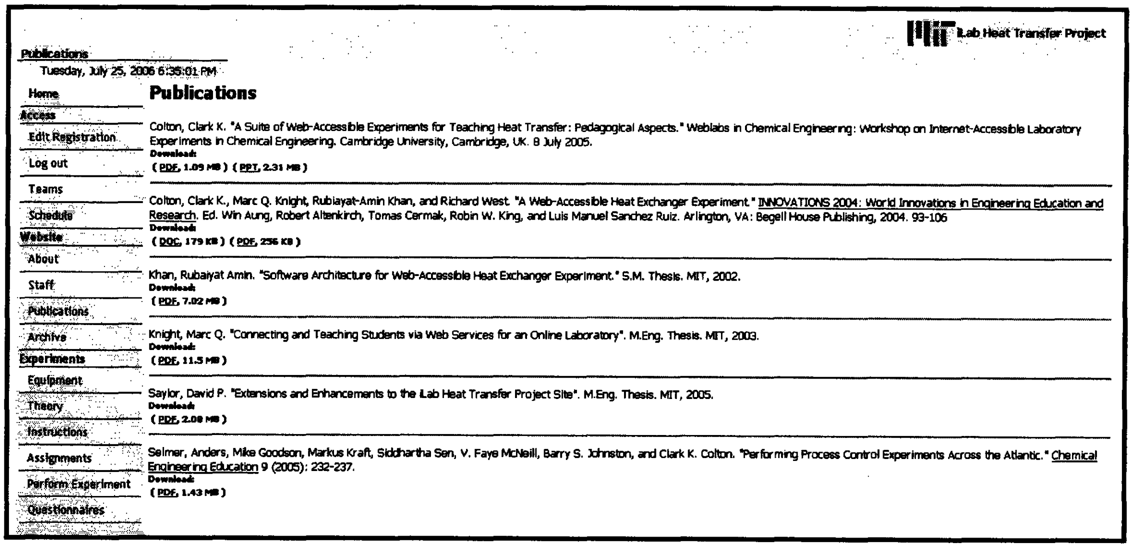


Figure 3-2: Publications page.

When uploaded, a copy of the original document file is transferred to the server and stored in the appropriate directory for the document type. An entry for the uploaded document file, containing the user-supplied document information, is added to the table `Files`. This table along with the table `FileCategories`, which contains the locations of document file directories, store all the information related to (not archived) documents posted on the website. The information from these tables is used to generate the links to documents on the web pages of the site. Descriptions of these tables are provided below.

`FileCategories`

- The `FileCategories` table stores, for each document category, the path (on the server) to the directory in which all document files of that category are stored. Each entry corresponds to a document category. The `Category` column (type `varchar:50`) contains the name of the category. The `DirPath` column (type `varchar:150`) contains the absolute path to the document file directory of the category.

`Files`

- The `Files` table stores information, entered by an administrator when uploading a document, describing each (not archived) document file posted to the website. Each entry corresponds to a document file. The `FileName` column (type `varchar:50`) contains the filename of the document. The `Category` column (type `varchar:50`) contains the category of the document. The `Title` column (type `varchar:500`) contains the title associated with the document. The `CourseName` column (type `varchar:50`) contains the name of the course with which the document is associated. The `SessionID` (type `varchar:36`) contains the ID of the session with which the document is associated.

3.1.2 Management of Existing Documents

The second section of the document management interface pertains to the management of documents already added to the website. As Figure 3-1 shows, this section contains a list of the (five) recognized document categories. Clicking on the blue arrow in the bottom right-hand corner of one of the list items reveals a grid with descriptions (loaded from the `Files` table) of each document of the corresponding category (not yet archived). Figure 3-3 shows the "assignment" category list item selected with information for two documents listed: the filename, title, course and session of each document are displayed. Located to the left of each document listing are buttons, labeled "Delete" and "Edit", which, respectively, allow deleting of the document (and its associated information) and editing of its associated information.

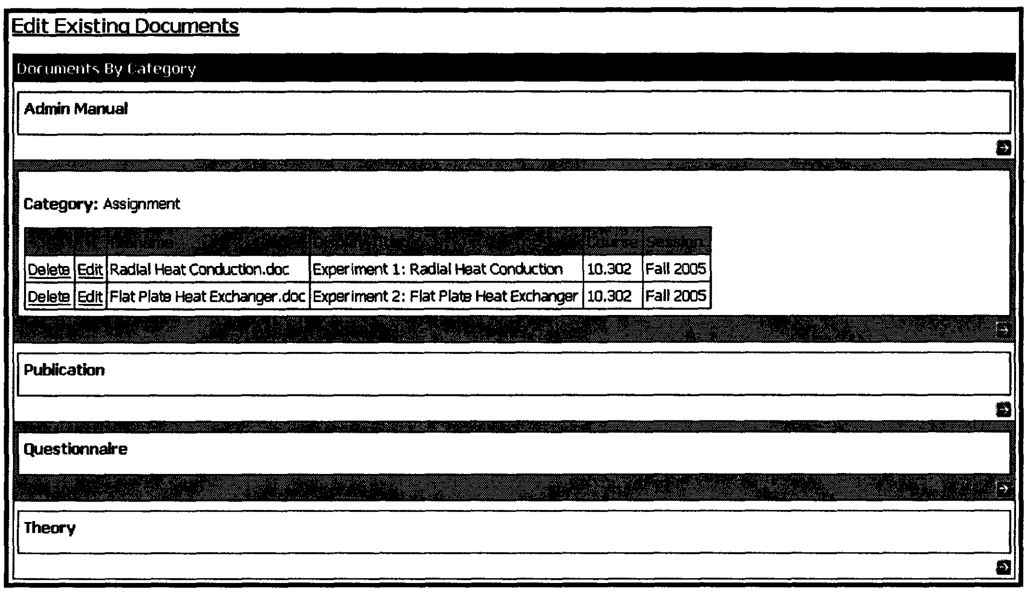


Figure 3-3: Document information management section of document management interface with Assignment category selected.

As seen in Figure 3-4, clicking on the Edit button of a document listing displays fields that allow editing of the descriptive information associated with the document. Doing so also causes the Edit button to be replaced by two new buttons labeled "Update" and "Cancel." Clicking on the Update button applies any changes made to the fields (i.e. updates the entry for the document in the `Files` table), while clicking on the "Cancel" button cancels the application of any changes made to the fields.

As seen in Figure 3-5, the clicking on the Delete button of a document listing displays a confirmation dialog at the top of the page. If the "Yes" button is clicked, all information for the document is deleted (i.e. the entry for the document is removed from the `Files` table) and a second confirmation dialog is presented. As Figure 3-6 shows, the second dialog asks permission to delete the document file that is residing of the server: clicking the "Yes" button deletes the file, while clicking the "No" button leaves the file on the server. It should be noted that answering the initial confirmation dialog in the affirmative removes any listing of the document from the website as all document-related pages (except the archive) retrieve information about existing documents from the `Files` table.

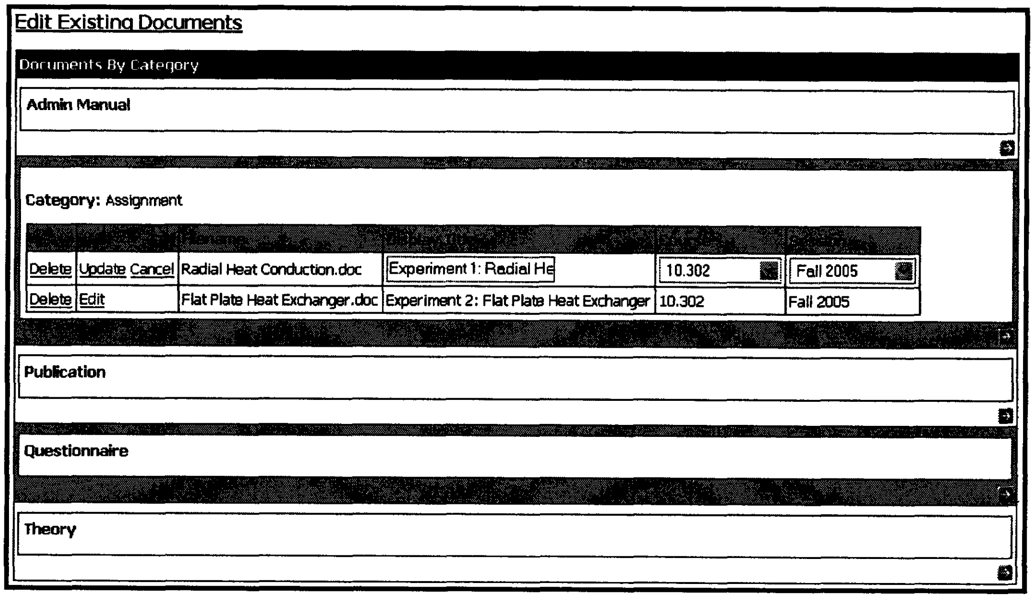


Figure 3-4: Document information management section of document management interface after clicking Edit button for "Radial Heat Conduction.doc" document listing.

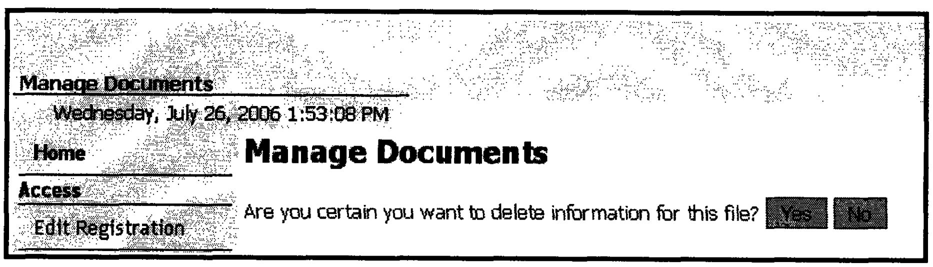


Figure 3-5: Confirmation dialog for deletion of document listing.

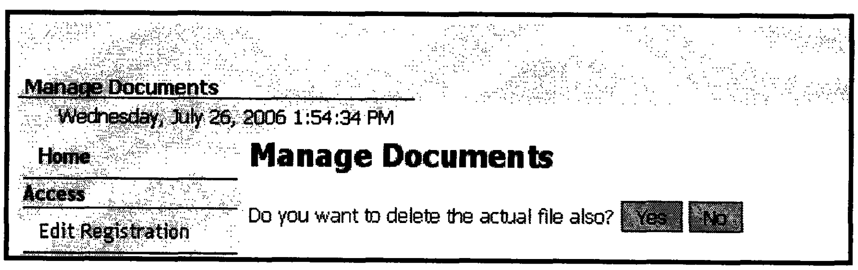


Figure 3-6: Confirmation dialog for deletion of document file.

3.2 Archival

Each course that works with the iLab Heat Transfer Project generates content, such as assignments for laboratory work and discussions of heat transfer theory, which can serve as a valuable resource for future users of the website. As such, the iLab Heat Transfer Project website currently maintains an archive, pictured in Figure 3-7, with links to content from past sessions of courses that have worked with the project. Previously, adding content from a course session to the archive required manually creating a new webpage with the content that one wished to maintain and manually editing the main archive page, pictured in Figure 3-7, to add a link to this new webpage. However, as part of the work for this thesis, a new feature was created that simplifies the process of archiving content by programmatically performing the aforementioned archival steps.

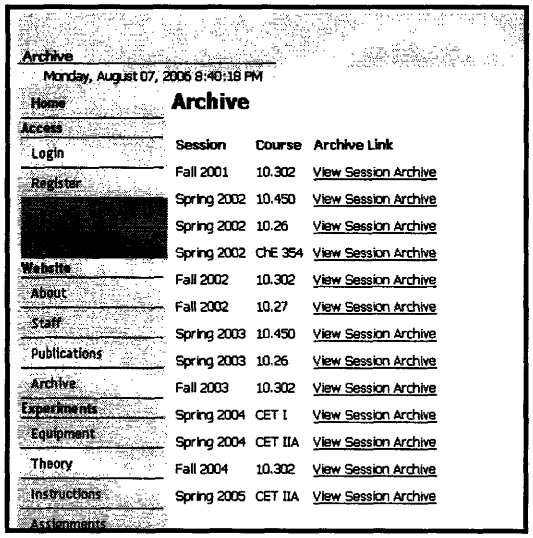


Figure 3-7: Main archive page.

3.2.1 Sessions

Before the initiation of the work of this thesis, there existed no concept of a session of course (e.g. Fall 2005) within the iLab Heat Transfer Project framework. Moreover, while students and teams were recognized as belonging to a particular course, documents simply existed without any means of associating them with a course (or a particular session of a course). To introduce the concept of sessions, the structure of the following database tables needed to be augmented with session information: `Files` (described in Section 3.1), `ArchivedUsers` (described in Section 3.2.2), `Courses` (described in Section 3.5), `Students` (described in Section 3.3). More importantly, a new table, `Sessions`, was created to store information about sessions:

`Sessions`

- The `Sessions` table stores information describing each course session. Each entry corresponds to a session. The `SessionName` column (type `varchar:50`) contains the name of the session (e.g. Fall 2005). The `SessionID` column (type `char:36`) contains an identifier for the session that is unique over all sessions. The `Course` column (type `varchar:30`) contains the course to which the session belongs. The `OrderDate` column (type `datetime:8`) contains a date that specifies the chronological order of the session. The `IsActive` column (type `bit:1`) indicates whether the session is active (i.e. has not been archived).

To accommodate the idea of sessions, the code of certain existing web pages also needed to be updated. The user registration pages were updated so that users are automatically assigned to the current session of the course for which they register. The course management page (see Section 3.5) was updated to allow administrators to specify the current session of course when registering a new course with the site. The course management page was also updated to allow a new session to be added to an existing course and to allow updating of the current session of an existing course. Finally, the batch registration page was updated to allow administrators to specify the session as well as the course for which users are being registered.

In addition to the regular sessions (e.g. Fall 2005, Summer 2006) that are associated with courses, all courses by default have a `[No Session]` session associated with them. The `[No Session]` session is a special session that is meant to be used in situations when an item needs to be associated with a course regardless of session. For example, instructors do not logically belong to a particular session of their courses. As such, all administrators are automatically assigned to the `[No Session]` session of a course.

3.2.2 Programmatic Archival

As described in Section 3.5, the course management page allows an administrator to initiate the archival of a session by simply pressing a button. When a session is archived, the `IsActive` field of its entry in the `Sessions` table is set to "0" to indicate that the session is inactive (i.e. archived). Database entries for all documents (located in the `Files` table) and all users (located in the `Students` table) associated with the session are migrated to the `ArchivedFiles` and `ArchivedUsers` tables, respectively. In addition, the actual document files are moved to a central archive folder. Within the archive folder, document files for an archived session are grouped into their own subfolder; the naming scheme for the session folder is *course_session* (e.g. 10.302_Fall 2005). Descriptions of the aforementioned database tables are provided below.

`ArchivedFiles`

- The `ArchivedFiles` table stores information describing each archived document file. Each entry corresponds to an archived document file. The `FileName` column (type `varchar:70`) contains the filename of the document. The `Category` column (type `varchar:50`) contains the category of the document. The `Title` column (type `varchar:500`) contains the title associated with the document. The `CourseName` column (type `varchar:50`) contains the name of the course with which the document is associated. The `SessionID` (type `varchar:36`) contains the ID of the session with which the document is associated.

`ArchivedUsers`

- The `ArchivedUsers` table stores information about users from archived courses. Each entry corresponds to an archived user. Users are added to the table when their course session is archived or when they complete an online questionnaire. The `UserID` column (type `char:36`) contains an identifier that is unique over all users. The `FirstName` column (type `varchar:30`) contains that first name of the user. The `LastName` column (type `varchar:30`) contains the last name of the user. The `Course` column (type `varchar:50`) contains the course to which the user belongs. The `SessionID` column (type `char:36`) contains the ID of the session to which the user belongs. The `Team` column (type `varchar:50`) contains the team to which the user belongs. The `Email` column (type `varchar:50`) contains the email address of the user. The `Login` column (type `varchar:30`) contains the username of the user. The `Registered` column (type `datetime:8`) contains the date and time that the user was registered for the website.

As show in Figure 3-7, the main page of the archive displays a listing for each archived session that has at least one associated document (i.e. the `ArchivedFiles` table contains at least one entry with ID of the session for its `SessionID` value). Clicking on an archive link for a session, causes a page to displayed listing links to all the documents associated with selected archived session. The information for the documents listed on this page is retrieved from the `ArchivedFiles` table. Figure 3-8 shows the session archive page for the Fall 2004 session of course 10.302. The archive page lists the three documents associated with the session; two of the documents have two file versions (Word Document, PDF). As such, the `ArchivedFiles` contains five entries corresponding to the five document files associated with the session.

Finally, note that the archival of a session, as it removes user entries from the `Students` table, prevents users from archived sessions from accessing the site via their archived accounts.

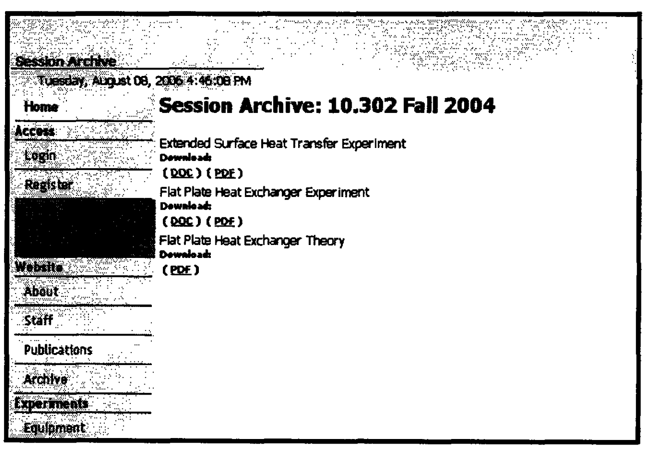


Figure 3-8: Archive page for Fall 2004 session of course 10.302.

3.3 User Management

As mentioned above, the previous user management interface provided administrators with a bare minimum of features. It simply displayed the name and username of a user and allowed the granting or removing of administrative privileges for a user. Therefore, a user management interface with a richer feature set was created to provide instructors with the ability to fully edit the registration information of their students.

As pictured in Figure 3-9, at the top of the user management interface is a group of dropdown lists, labeled "Course", "Session", and "User," with which a particular user maybe selected from among all users registered with the site. Upon selecting a course from the Course dropdown list, the Session dropdown list is loaded with the sessions for the selected course. Similarly, upon selecting a particular session, the User dropdown list is populated with those users, if any, belonging to the selected course and session.

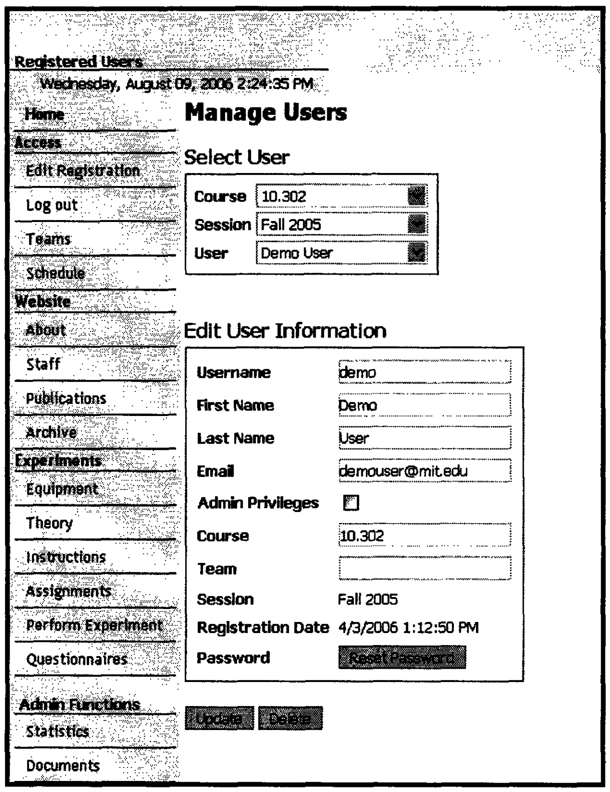


Figure 3-9: User management interface with registration information displayed for user Demo User of session Fall 2005 of course 10.302.

One caveat to the above description of the user selection process is the existence of the special list item `[Unregistered/No Course]` in the Course dropdown list. The `[Unregistered/No Course]` list item collects all users that are registered with an "unofficial" course (see Section 3.5) or that are registered with no course listing. As openness is desired, individuals are freely allowed to register and explore the site without the requirement of being a member of one of the courses that are officially working with the project. This special course list item is meant to catch all these potential users of the site. In addition, the session dropdown list is not displayed when this option is selected from the Course list: students with an unregistered course listing or with no course listing do not have a valid session listing.

Once a user has been selected from the User dropdown list, the registration information of the user is displayed (as pictured in Figure 3-9). The information that is displayed is the information entered by the user (or instructor) when the user was registered with the site. It is stored in the `Students` table:

`Students`

- The `Students` table stores the registration information for each user. Each entry corresponds to a registered user. The `UserID` column (type `char:36`) contains an identifier that is unique over all users. The `Login` column (type `varchar:30`) contains the username of the user. The `Password` column (type `varchar:30`) contains the password of the user. The `FirstName` column (type `varchar:30`) contains that first name of the user. The `LastName` column (type `varchar:30`) contains the last name of the user. The `Email` column (type `varchar:50`) contains the email address of the user. The `IsAdministator` column (type `bit:1`) indicates whether the user has administrative privileges. The `Course` column (type `varchar:50`) contains the course to which the user belongs. The `Team` column (type `varchar:50`) contains the team to which the user belongs. The `Registered` column (type `varchar:100`) contains the date and time that the user was registered for the website. The `SessionID` column (type `varchar:36`) contains the ID of the session to which the user belongs.

As shown in Figure 3-9, all registration information stored (in the `Students` table) for a selected user is presented, and, with the exception of registration date/time and session, all information associated with a selected user is directly editable. Any updates made to the user information fields are committed to the `Students` table by clicking the Update button. The exception to this is the updating of a user's password: clicking on the "Reset Password" button immediately replaces the password of the selected user with a randomly generated alphanumeric string (nine characters in length) and displays it. It should also be noted that while the session information for a user is not directly editable here, it is appropriately updated given other changes made to the information for a user. In particular, giving a user administrative privileges causes her associated session to be changed to `[No Session]` (see Section 3.2.1), while removing administrative privileges reverts her associated session to the current session for the associated course. Similarly, associating a user with a new course changes the associated session to the current session for the newly associated course.

In addition to updating user information, the user management interface also allows all information for a user to be deleted. To delete the information for the selected user (i.e. delete the entry for the user in the `Students` table), an administrator can simply press the Delete button. A dialog will be presented that asks for confirmation for the deletion of the registration information for the selected user. Clicking the "Yes" button will delete the relevant user registration information, while clicking "No" will cancel the deletion request.

3.4 Site Announcements

The prior administrator interface for posting announcements to the front page of the website, while useful, lacked the ability to delete posted announcements. Deleting announcements previously required manually clearing the text file in which announcements are stored. The announcement management interface was extended (see Figure 3-10) to allow administrators to perform this task from the iLab Heat Transfer Project website.

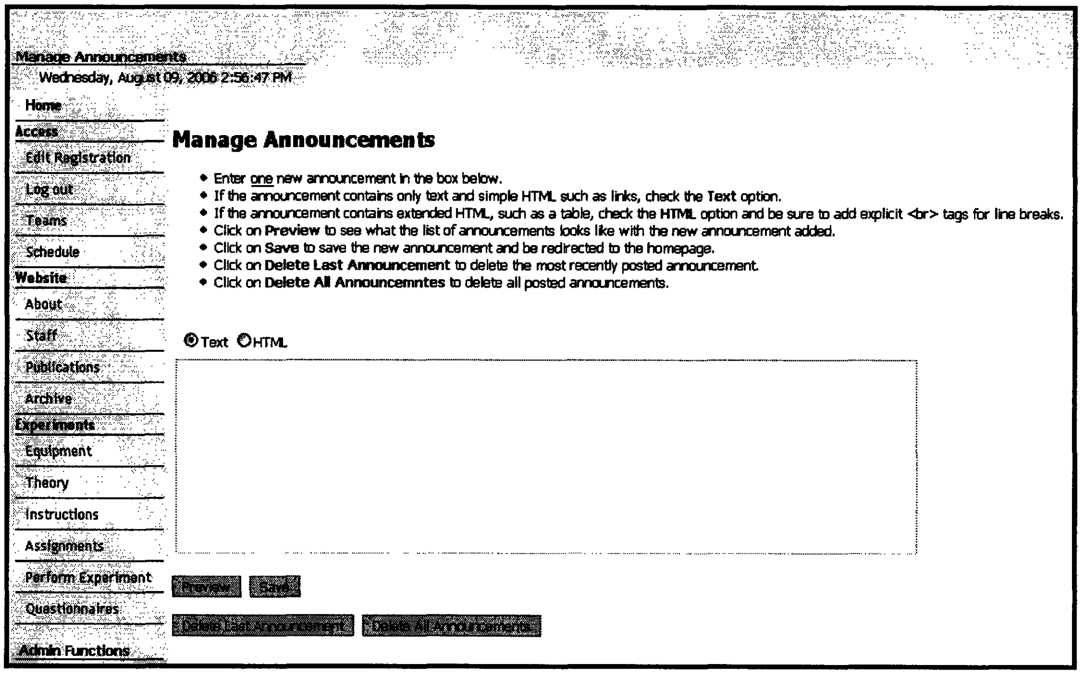


Figure 3-10: Announcement management interface.

An option has been added to the announcement management interface to allow for the deletion of the last (most recently) posted announcement. This option, in conjunction with the available announcement preview feature, is useful in correcting mistakes. Upon clicking on the "Delete Last Announcement" button, the most recently posted announcement is removed from the front page of the website (and the source text file). As shown in Figure 3-11, the announcement that has been deleted is displayed, highlighted in red text, at the top of the announcement management interface.

Another option has been added that allows for the deletion of all announcements posted to the front page of the website. Upon clicking on the "Delete All Announcements" button, all announcements are removed from the front page of the website (and the source text file); a simple confirmation message announcing successful deletion is displayed at the top of the page.

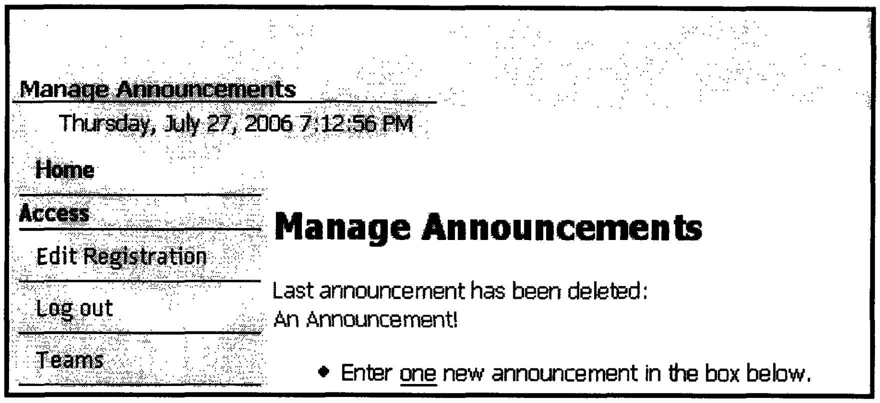


Figure 3-11: Confirmation message that last posted announcement ("An Announcement!") has been deleted.

3.5 Course Management

The purpose of the course management interface is to allow the editing of information concerning the courses officially working with the iLab Heat Transfer Project. The interface allows for the creation and deletion of courses as well as the management of course details—such as the creation of student teams and the specification of the current session. While the basic shell for this interface existed before the commencement of the work of this thesis, the majority of the functionality detailed below was added or corrected for this thesis.

As previously mentioned (see Section 3.3), anyone is free to register and examine the content available at the iLab Heat Transfer Project site. However, the course management interface, like other administrative features, is meant to track and provide additional abilities to instructors of courses officially working with the project. With this feature, instructors are able to register there course with the website.

3.5.1 Addition of a New Course

When adding a course to the site, as shown in Figure 3-12, an instructor needs to supply three pieces of information: a course name, an initial amount of teams, and the name of the current session. After entering this information in the fields of the "Add New Course" section and pressing the "Add Course" button, the course information is added to the database. Specifically, the `Courses`, `CourseTeams`, and `Sessions` tables are updated with the provided information describing the new course. See Section 3.2.1 for a description of the `Sessions` table; descriptions of the `Courses` and `CourseTeams` tables are provided below:

`Courses`

- The `Courses` table stores information for each course. Each entry corresponds to a registered course. The `CourseName` column (type `varchar:50`) contains the name of the course. The `CurrentSessionID` column (type `char:36`) contains the ID of the current session of the course.

CourseTeams

- The `CourseTeams` table stores information for each team of a registered course. Each entry corresponds to a team of a registered course. The `CourseName` column (type `varchar:50`) contains the name of the course to which the team belongs. The `TeamNumber` column (type `varchar:50`) contains the name of the team. The `Num` column (type `int:4`) contains a nominal index value (one or greater) used to order teams: at creation a team is assigned the next highest available index value.

Upon clicking on the "Add Course" button, two new entries are created in the `Sessions` table: one is entry is created for the specified "current session" of the course and one is created for the `[No Session]` session associated with the course. A new entry is created in the `Courses` table for the new course with the session ID of its current session. Lastly, new entries are created in the `CourseTeams` table for the specified amount of new teams. Teams are created with names of the format "Team *n*", where *n* is an integer 1 or greater.

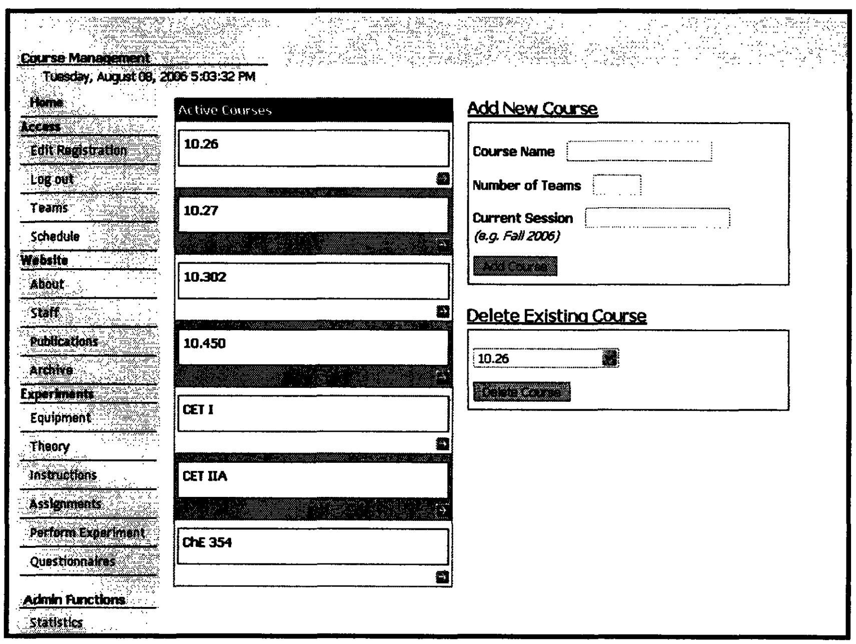


Figure 3-12: Course management interface.

3.5.2 Management of Course Teams and Sessions

After a new course is created, a list item for the course is displayed in the "Active Courses" list. Clicking the blue arrow button in the corner of the list item for a course causes a detail view of the team and session information for the course to be displayed (see Figure 3-13).

In the detail view, the name of the course is displayed followed by the number of teams assigned to the course. Beneath this is a dropdown list, loaded with the teams of the course, and two buttons labeled "Add New Team" and "Delete Selected Team." The former button allows additional teams to be added for the course while the latter allows the team selected from the dropdown list to be deleted from the collection teams assigned to the course. Clicking the "Add New Team" button causes a new entry to be added to the `CourseTeams` table; the new entry is associated with the course and has the name "Team *n*", where *n* is the next highest unused team number for the course. Conversely, clicking the "Delete Selected Team" button causes the deletion of the entry in the `CourseTeams` table for the team currently selected from the dropdown list. In both situations, the dropdown list of teams and the displayed number of teams are updated accordingly.

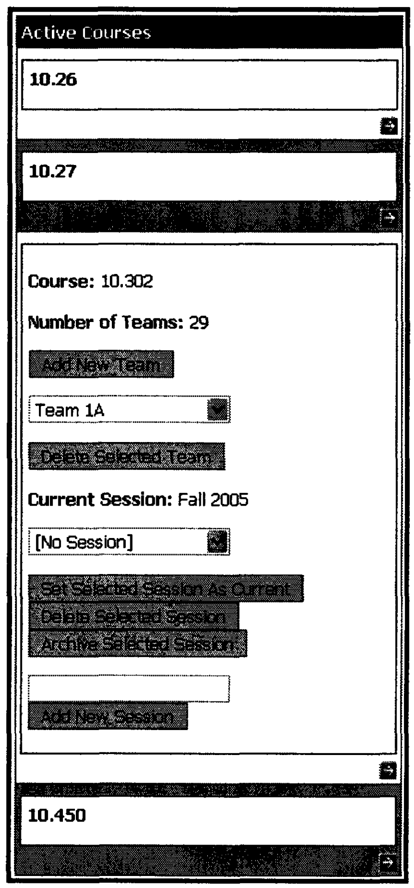


Figure 3-13: Course management interface with detail view for selected course (10.302).

Located below the team information in the detail view of a course is a section pertaining to session information. The name of current session is displayed next to the "Current Session" label. Below this is a dropdown list loaded with the active sessions of the course (i.e. those yet to be archived), which usually consists of the current session and the special `[No Session]` session.

The three buttons located immediately below the dropdown list of active sessions, labeled "Set Selected Session As Current," "Delete Selected Session," and "Archive

Selected Session," with respect to the selected session from the dropdown list, set it as the current session of the course, delete it, and archive it, respectively. The "Set Selected Session As Current" button, when clicked, updates the `CurrentSessionID` field (of the entry in the `Courses` table that corresponds to the course) to the session ID of the selected session. The "Delete Selected Session" button, when clicked, deletes the entry for the selected session from the `Sessions` table. If the deleted session happens to be the current session for the course, the `[No Session]` session is made the current session of the course by default. (The `[No Session]` session of a course cannot be deleted.) Finally, the "Archive Selected Session" button, when clicked, archives the session as described in Section 3.2. If the archived session happens to be the current session of a course, the `[No Session]` session is made the current session of the course by default. (The `[No Session]` session of a course cannot be archived.)

Located at the bottom of the detail view is a field that allows a new session to be added to the course. Clicking the "Add New Session" button will create a new session for the course with the name specified in the text field. An entry for the new session is added to the `Sessions` table.

3.5.3 Deletion of an Existing Course

The last feature provided by the course management interface allows a course to be deleted. As pictured in Figure 3-12, beneath the heading "Delete Existing Course" is a dropdown list containing the courses registered with the site. Clicking on the "Delete Course" button located below the dropdown list causes the course to be deleted. This includes deletion from the `Courses` table of the entry for the course, deletion from the `Sessions` table of any entries for sessions associated with the course, and deletion from the `CourseTeams` table of any entries for teams associated with the course. Note, however, that deletion of a course is only possible if the course has no registered students and no archived sessions. If an administrator truly wishes to delete a course from the site, which has no archived sessions, he may first delete the students registered to the course, via the user management interface, and then delete the course using this feature.

3.6 Experiment Management

There previously existed no means by which an administrator could, by way of the website, specify the currently active experiment (i.e. the experiment for which the relevant lab equipment is connected to the server and running). Changing the active experiment, with reference to the website, requires modifying which experiment is advertised on the front page of the site (see Figure 3-14) and providing a link to the appropriate experiment interface page on the Perform Experiment page (Figure 3-15). Making either of these changes used to require manually modifying the underlying code of these two web pages.

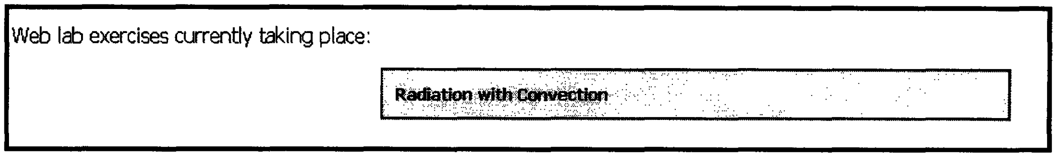


Figure 3-14: Advertisement on the front page of the website that the Radiation with Convection Experiment is active.

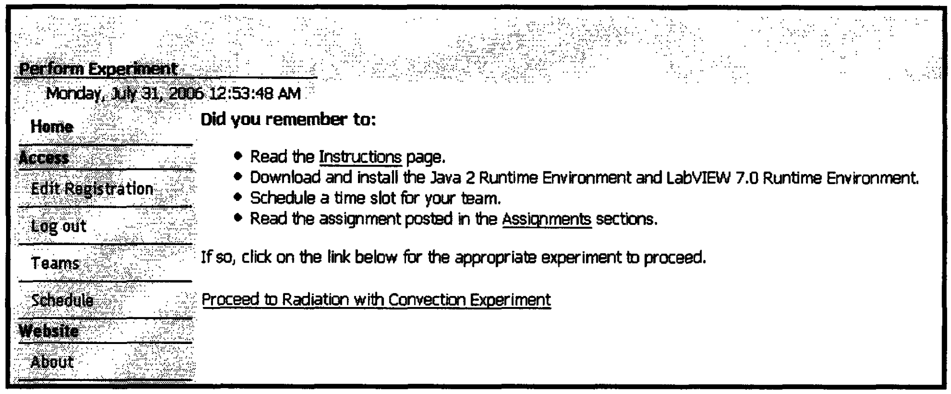


Figure 3-15: Perform Experiment page advertising link to Radiation with Convection Experiment interface page.

An interface, shown in Figure 3-16, has been created to allow an administrator to manage experiments via the website. The experiment management interface provides a means to modify certain key pieces of information concerning experiment interface pages. The information displayed by the experiment management interface is retrieved from the `Experiments` table, which is described below.

`Experiments`

- The `Experiments` table stores information about available experiments. Each entry corresponds to an experiment (interface page). The `Title` column (type `varchar:50`) contains the title of the experiment. The `URL` column (type `varchar:100`) contains the URL at which the experiment interface page can be accessed. The `IsActive` column (type `bit:1`) indicates whether the experiment is currently active. The `ID` column (type `char:36`) contains an identifier for the experiment that is unique over all experiments.

Located at the top of the experiment management page is a grid that lists information for each registered experiment. Clicking the Edit button of an experiment listing causes fields to displayed that allow the information for the experiment to be updated. Clicking on the Edit button also causes the button to be replaced by two buttons labeled "Update" and "Cancel" (see Figure 3-17). The Update button causes any changes made to the experiment information to be committed, while the Cancel button cancels any changes made to the information. Note that selecting the "Active" checkbox for an experiment listing causes the experiment to be advertised on the front page of the site and causes a link to the experiment interface page to be added to the Perform Experiment page. Deselecting the "Active" checkbox undoes this.

To delete the information for an experiment (i.e. remove the entry for the experiment form the `Experiments` table), an administrator can simply press the Delete button of the experiment listing. A dialog will be presented that asks for confirmation for the deletion of the information for the experiment. Clicking the "Yes" button will delete the relevant experiment information, while clicking "No" will cancel the deletion request.

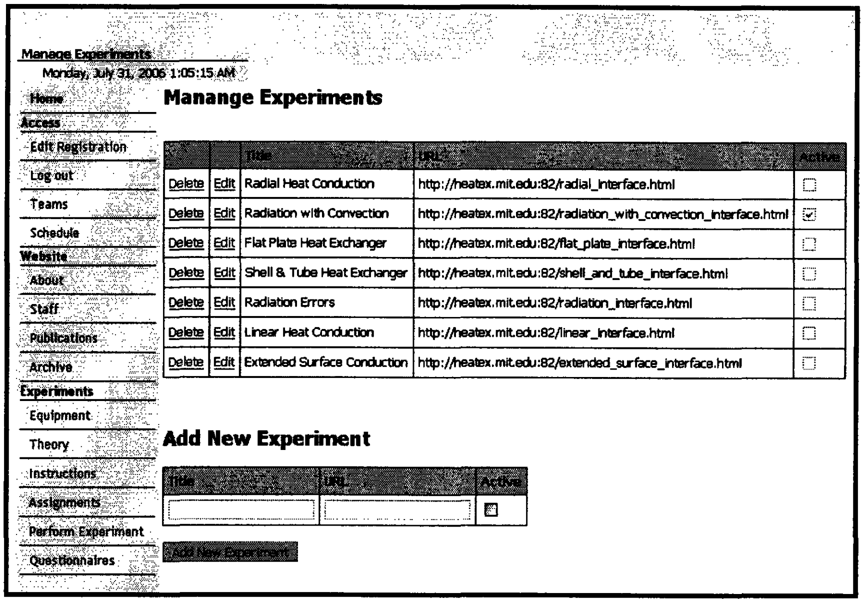


Figure 3-16: Experiment management interface.

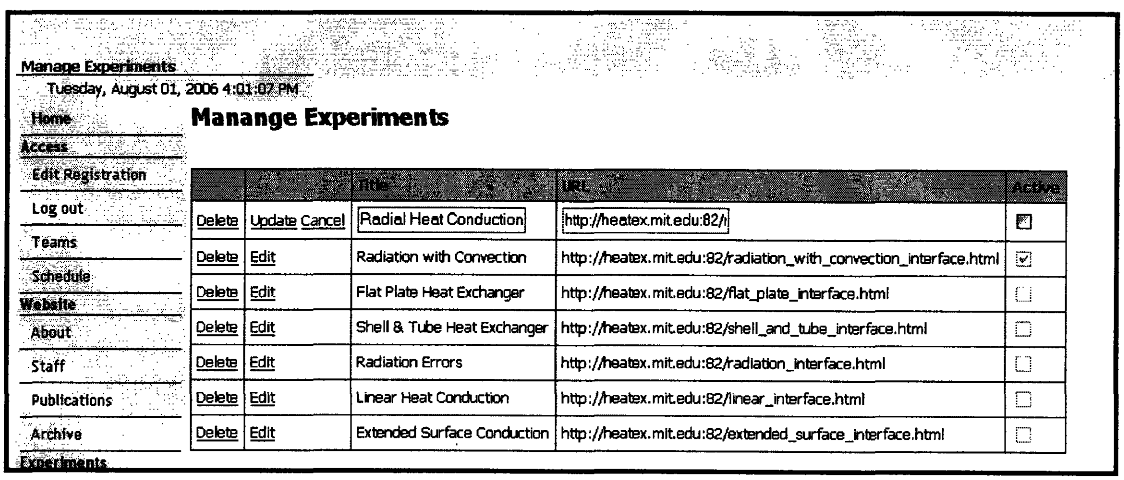


Figure 3-17: Experiment management interface after clicking Edit button for the Radial Heat Conduction Experiment listing.

Figure 3-18: Confirmation dialog for deletion of information for the Radial Heat Conduction Experiment.

The experiment management interface also contains a section at the bottom that allows an administrator to add information for a new experiment (see Figure 3-16). After specifying the title of the new experiment, the address of the experiment interface page, and the activity state of the experiment, an administrator can click on the "Add New Experiment" button to add the information for the experiment. Upon clicking the "Add New Experiment" button, a unique ID is created for the experiment and a new entry is added to the `Experiments` table containing the ID and the information entered by the administrator. The experiment list on the experiment management interface is updated with a listing for the new experiment.

4 Questionnaire Analysis

As previously mentioned, an online questionnaire form exists that allows the entry of student responses to a collection of questions on their experiences using different aspects of the iLab Heat Transfer Project. However, concerns about the functionality of the questionnaire system prompted the use of paper questionnaire forms to collect user responses. Questionnaires were provided to students taking the Fall 2005 edition of the MIT course 10.302. Students were asked to complete questionnaires about their experiences with the site after the completion of each of two experiments: the (1) Radial Heat Conduction Experiment and the (2) Flat Plate Heat Exchanger Experiment. Students were not required to complete the provided questionnaires, however they were informed that they would receive bonus points for completing the questionnaires.

4.1 Redesign of the Questionnaire Framework

The previous questionnaire framework (i.e. the structure of the database tables that store questionnaires and user responses and the questionnaire-related web pages that interact with these database tables) required redesigning. While the scheme associated responses with a nominal question ID, there was no means, by way of the contents of database tables, to match responses to the original text of the associated question. The addition of a feature to save HTML versions of completed questionnaires serves the basic purpose of archiving the questionnaire data (in a state where responses and the original question text are closely associated), however it does not readily allow manipulation of the responses for analysis. Furthermore, the previous scheme could not support a question that existed independent of a questionnaire, therefore it did not lend itself to the reuse of questions in creating new questionnaires nor did it facilitate the comparison of responses to the same question over different questionnaires. The means of storing questionnaire information in the database was altered to address these issues.

Four new database tables were created to store information pertaining to questionnaires: `Questionnaires`, `QItems`, `QItemTypes`, and `Responses`.

`Questionnaires`

- The `Questionnaires` table stores information about questionnaires. Each entry corresponds to a questionnaire. The `QuestionnaireID` column (type `int:4`) contains an identifier for the questionnaire that is unique over all questionnaires. The `Title` column (type `varchar:50`) contains the title of the questionnaire. The `PostDate` column (type `datetime:8`) contains the date that a questionnaire was posted (i.e. made available to users of the site). The `Description` column (type `varchar:1000`) contains an brief description of the questionnaire. The `QItems` (type `varchar:250`) column contains the ID of the items (e.g. questions, section headings) that compose the questionnaire.

`QItems`

- The `QItems` table stores information about the individual items (e.g. questions, section headings) that compose questionnaires. Each entry represents an individual questionnaire item. The `QItemID` column (type `int:4`) contains an identifier for the questionnaire item that is unique over all questionnaire items. The `QItemType` column (type `tinyint:1`) contains an identifier of the type of the questionnaire item. The `Params` column (type `varchar:250`) contains the parameters, which vary by questionnaire item type, that define the questionnaire item. The `BaseQItem` column (type `int:4`) allows specification of a different questionnaire item from which this questionnaire item is meant to be only cosmetically different.

`QItemTypes`

- The `QItemTypes` table stores information about the supported types of questionnaire items. Each entry corresponds to a questionnaire item type. The `QItemTypeID` column (type `tinyint:1`) contains an identifier for the questionnaire item type that is unique over all questionnaire item types. The `Name` column (type `varchar:50`) contains the name of the questionnaire item type.

`Responses`

- The `Responses` table stores responses to questionnaires from users. Each entry corresponds to a response from a user to a single questionnaire item. The `UserID` column (type `char:36`) contains the unique ID of the user who provided the response. The `Questionnaire` column (type `int:4`) contains the unique ID of the enclosing questionnaire of the questionnaire item that prompted the response. The `QItem` column (type `int:4`) contains the unique ID of the questionnaire item that prompted the response. The `UserResponse` column (type `varchar:600`) contains the contents of the response. The `Hashcode` column (type `varchar:50`) contains a hash of the contents of the other fields of the entry that is meant to verify the authenticity of the response data.

The questionnaire framework divides questionnaires into individual questionnaire items. A questionnaire item can be a section heading, a section/question description, or one of several kinds of questions. The different types of questionnaire items that are currently supported are stored in the `QItemTypes` table. Information describing the individual items that compose questionnaires is stored in the `QItems` table. Each entry in the table specifies an individual questionnaire item. A Questionnaire is defined, or represented, by an entry in the `Questionnaires` table. The entry for a questionnaire specifies the items, in order, that compose a questionnaire. This specification of questionnaire items independent of the questionnaires that contain them allows for easy reuse of questionnaire items across questionnaires and easy comparison of the content of questionnaires. Moreover, as the questionnaire framework now actually stores the contents of questionnaires (i.e. questionnaire items) in a database table, it is possible to match user responses to the text of the questions that solicited them.

Like questionnaire items, user responses to the individual items of a particular questionnaire are stored as individual entries in the `Responses` table. Among other things, this particular design prevents the need to assume specific details of the structure of current or future questionnaires: questionnaires with varying amounts or types of questions can be accommodated.

4.1.1 Questionnaire Item Types

The questionnaire framework currently supports six types of questionnaire items: section, description, text-valued question, numeric-valued question, collection option question, and range option question. Each of these questionnaire item types requires different parameters. For example, questionnaire items of the section and description types only need the specification of their text, while questionnaire items of the collection option type require the specification of the names their different response options (in addition to their text). The `Params` column of the `QItems` table allows specification of the parameters for a questionnaire item: parameters are separated by a vertical bar (|). Below are detailed descriptions of the supported questionnaire item types and their parameters.

4.1.1.1 Sections

The "section" type is used to describe the section headings of a questionnaire. The only parameter expected for the section type is the text of the heading. An example of the parameter specification for a section is provided below.

Learning Experiences

Note that questionnaire items of the section type do not take users responses. As such, the `Responses` table contains no entries for questionnaire items of this type.

4.1.1.2 Descriptions

The "description" type is used for section or question descriptions. In addition to the header, a section may need to provide a description of its contents or purpose. Similarly, a description may need to be provided for a group of related questions. The description type is meant to be used for these purposes. As with the section type, the only parameter expected for the description type is the text of the description. An example of the parameter specification for a description is provided below.

> Please rate how well the following phrases describe the mental operations you used when completing the data analysis.

Note that questionnaire items of the description type do not take users responses. As such, the `Responses` table contains no entries for questionnaire items of this type.

4.1.1.3 Text-valued Questions

The "text-valued question" type is used for questions for which a text response is expected. The text-valued question type is generally used for questionnaire items that ask for comments from the responder. The response to a text-valued question is interpreted as a text string. The only parameter expected for the text-valued question type is the text of the question. An example of the parameter specification for a text-valued question is provided below.

> Please comment on your overall experience.

4.1.1.4 Numeric-valued Questions

The "numeric-valued question" type is used for questions for which a numeric response is expected. The response to a numeric-valued question is interpreted as a floating-point value. As with the text-valued question type, the only parameter expected for the numeric-valued question type is text of the question. An example of the parameter specification for a numeric-valued question is provided below.

> How many minutes did it take you to complete the experiment?

4.1.1.5 Collection Option Questions

The "collection option question" type is used for questions for which a (limited) collection of response options is provided. A collection option question requires a responder select one (or more) of a predefined set of response options. No restrictions are placed on the options that may be provided for this question item type and all options are treated as strings of text. Unlike the previously discussed questionnaire item types, three *or more* parameters are expected for the collection option question type. The first parameter is expected to be the text of the question. The second parameter is expected to be a truth-value (true, false) indicating whether a responder may select multiple response options. Finally, one or more parameters are expected to specify the names of the options to be presented.

An example of the parameter specification for a collection option question is provided below. The question in the example would present the question "Please check where you conducted the experiment:" and provide the ability to select *exactly one* of the options "In Lab" and "Remotely." As mentioned above, vertical bars are used to separate parameters.

```
Please check where you conducted the experiment:|false|In Lab|Remotely
```

4.1.1.6 Range Option Questions

The "range option question" type is used for questions for which a (limited) range of numeric response options is provided. A range option question requires a responder select a value from a predefined range of values. A range of integral values is the most logical use of the range option question type, however no restrictions are imposed that prevent use of the type with a floating-point range. Use of this type requires specification of the minimum and maximum value of the range and the "step size" in between values. In addition to these values, labels (e.g. "strongly disagree", "strongly agree") are required for the minimum and maximum values to describe what the range of values means. Formally, the five parameters required for the range option question type are (1) the text of the question, (2) the minimum response range value, (3) the maximum response range value, (4) the minimum response range label, (4) the maximum response range label, and (5) the response range step size.

An example of the parameter specification for a range option question is provided below. The example describes a range option question with a minimum value of 1, a maximum value of 7, and a step size of 1 that would cause the following range of values to be presented as response options: 1, 2, 3, 4, 5, 6, and 7. As mentioned above, vertical bars are used to separate parameters.

```
The instructions were clear.|1|7|strongly disagree|strongly agree|1
```

Note that the specified step size does not have to evenly divide the min-max range. The set of response values is created from the min-max-step size specifications by starting with the minimum value and generating values with the desired step size until reaching the maximum value. Therefore, if a step size of 4 had been used with the previous example, the following response options would be generated: 1, 5, and 7. In both of these cases, as with all range option questions, only one response option may be selected.

4.1.2 Questionnaire Content Description

The content of a questionnaire is specified by the `QItems` field of the entry for the questionnaire in the `Questionnaires` table. Questionnaire item IDs are used to reference questionnaire items. Questionnaire items appear on a questionnaire in the order that their IDs are listed in `QItems` field.

Questionnaire item IDs can be specified using either of two formats. If a group of questionnaire items with consecutive IDs is to be specified, it is sufficient to specify the minimum and maximum ends of the ID range with a hyphen. Alternatively, questionnaire items can be specified by listing their IDs separated by commas. A comma can also be used to combine groups of questionnaire items using the two formats. The following example illustrates these formats of specifying questionnaire items: the example specifies the questionnaire items 1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 99, 14, and 15 in that order.

```
1-7,10,11,12,13,99,14-15
```

In addition to simply specifying which questionnaire items appear on a questionnaire, it is also possible to specify the structure of a questionnaire. A vertical bar can be used to denote the top-level or main sections of a questionnaire. Subsections can also be denoted by the use of parenthesis: the questionnaire item ID listed before a set of parenthesis is taken to be the subsection header and the questionnaire item IDs listed within the parenthesis compose the subsection. Parenthesis can also be embedded to create further subsections. The following example illustrates the use of vertical bars and parenthesis to provide the structure of a questionnaire. The example specifies a questionnaire with four main sections. The second main section has a subsection where questionnaire item 9 is the header. The third main section has a subsection where questionnaire item 72 is the header; this subsection has a subsection where questionnaire item 24 is the header. Note that while there is no requirement that the header questionnaire items are of type section, it is logical that are of this type.

```
1-7|8,63,64,9(10-13)|71,72(22,24(50-54,56,58),62),88-90|100-104
```

4.2 Questionnaire Data Presentation Features

An interface has been created that provides several means of viewing the questionnaire responses stored in the `Responses` table. The questionnaire statistics interface allows a user to view the responses to a questionnaire from an individual responder as well as response averages over user-defined groups of responders. In particular, as described below in detail, three modes of viewing questionnaire data are available: individual, aggregate-individual, and aggregate.

4.2.1 Modes of Data Presentation

4.2.1.1 Individual Mode

In "individual mode," it is possible to view the responses to a questionnaire from a single user. When this mode is selected, as shown in Figure 4-1, a questionnaire dropdown list allows the selection of a questionnaire and a course dropdown list allows the selection of a course. A responder dropdown list is populated with the users of the selected course that have responded to the selected questionnaire. Below these dropdown lists, displayed for each item of the selected questionnaire is the (1) ID of the questionnaire item, the (2) text of the questionnaire item, and the (3) response of the selected user to the questionnaire item.

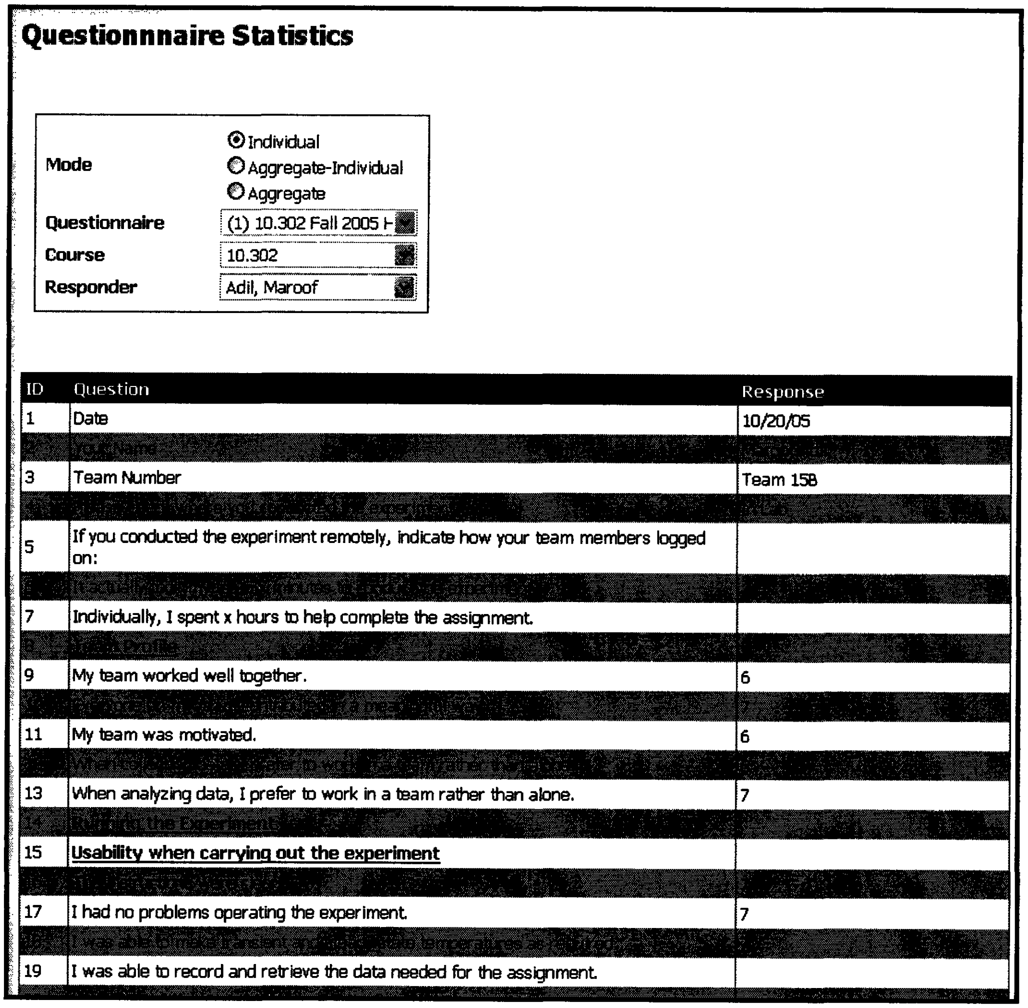


Figure 4-1: Questionnaire statistics interface in individual mode.

4.2.1.2 Aggregate-Individual Mode

"Aggregate-individual mode" allows the responses of all users to a single questionnaire item to be viewed at once. As shown in Figure 4-2, questionnaire and course dropdown lists allow the selection of a questionnaire and a course, respectively. All of the items of the selected questionnaire are displayed accompanied by their IDs and "Select" links.

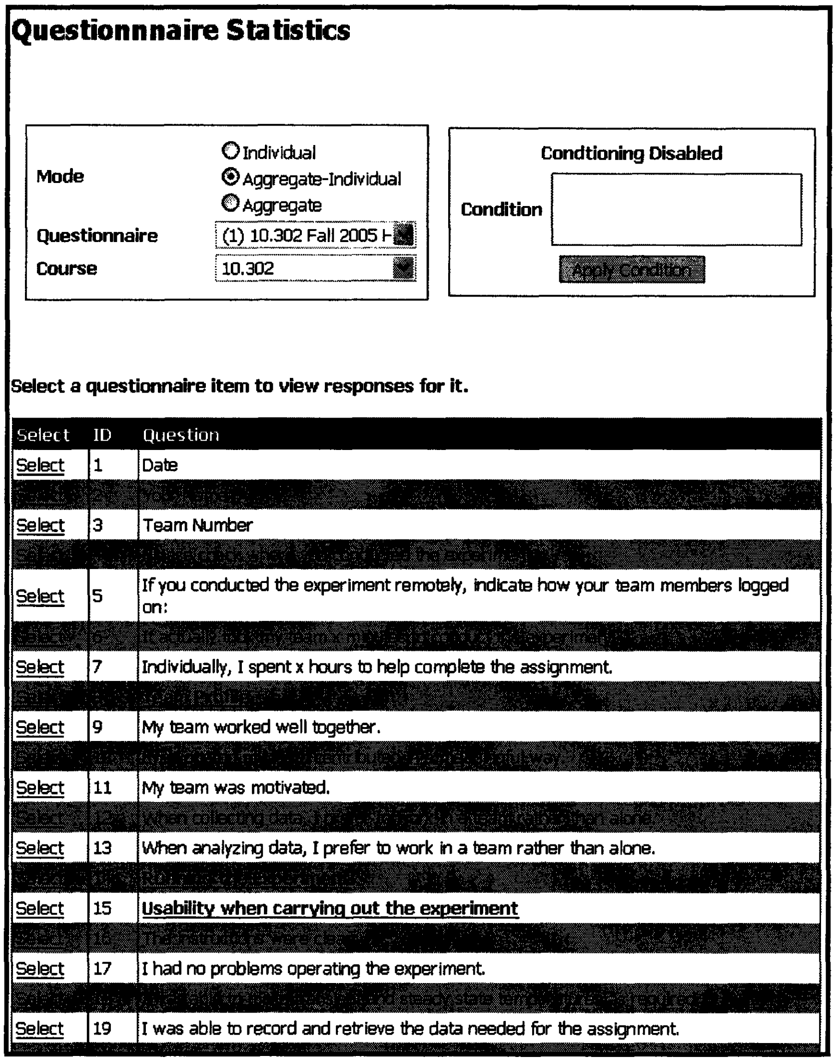


Figure 4-2: Questionnaire statistics interface in aggregate-individual mode: questionnaire item selection page.

Clicking on the "Select" link next to a questionnaire item loads the responses to that questionnaire item from every user of the selected course (see Figure 4-3). Listed to the left of each response is the name of the user to whom it belongs. Listed at the top of the interface are the text and ID of the questionnaire item to which the listed responses correspond. Also listed at the top of the interface is the number of users that responded to the selected questionnaire. The button labeled "Select Another Questionnaire Item," reloads the original list of questionnaire items for the selected questionnaire, thereby allowing the responses to another questionnaire item to be viewed.

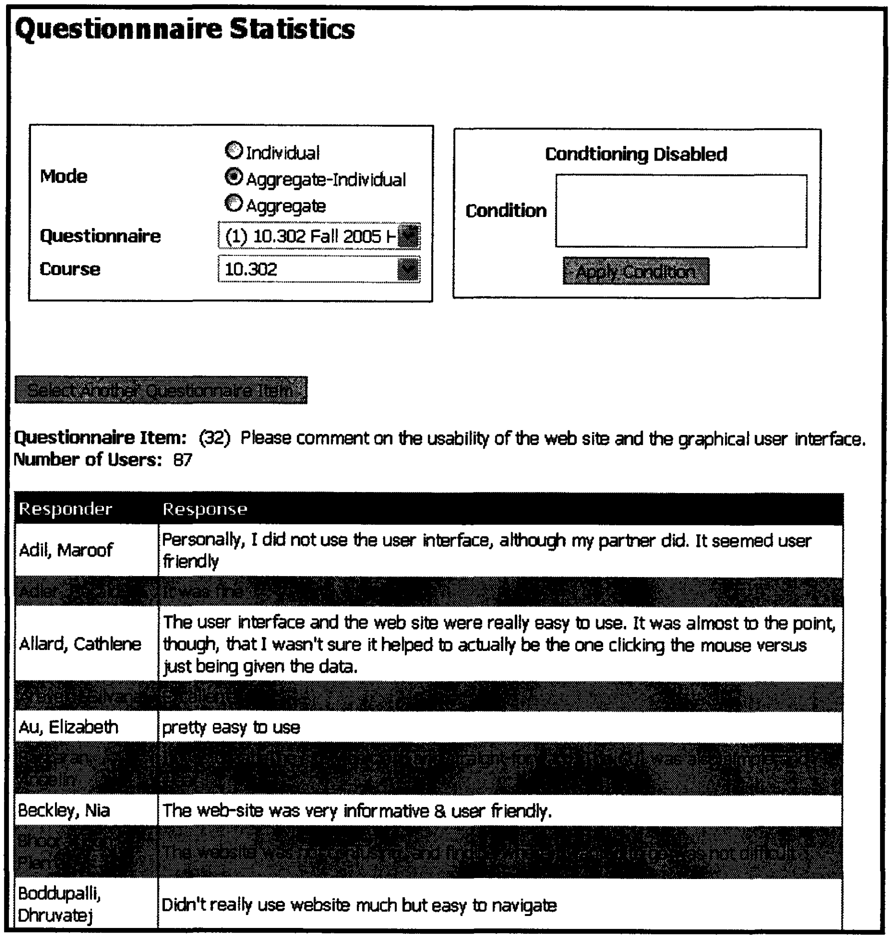


Figure 4-3: Questionnaire statistics interface in aggregate-individual mode: questionnaire item responses page.

4.2.1.3 Aggregate Mode

In "aggregate mode," for each item of a questionnaire, the average over all user responses is displayed. As shown in Figure 4-4, questionnaire and course dropdown lists allow the selection of a questionnaire and a course, respectively. For each item of the selected questionnaire with a numeric-valued response (e.g. numeric-valued questions, range option questions), an average (arithmetic mean) is taken over all responses from users of the selected course. Displayed in parenthesis next to each average is a two-tailed 95% confidence interval; the two values in parenthesis indicate the interval ends. The standard deviation (standard error) of responses is also displayed for each questionnaire item with a numeric-valued response. In addition, for questionnaire items that provide a set of options from which a responder may choose (e.g. collection option questions, range option questions), a frequency distribution over the options is also provided. Note that none of these statistics is provided for questionnaire items that request comments (e.g. text-valued questions).

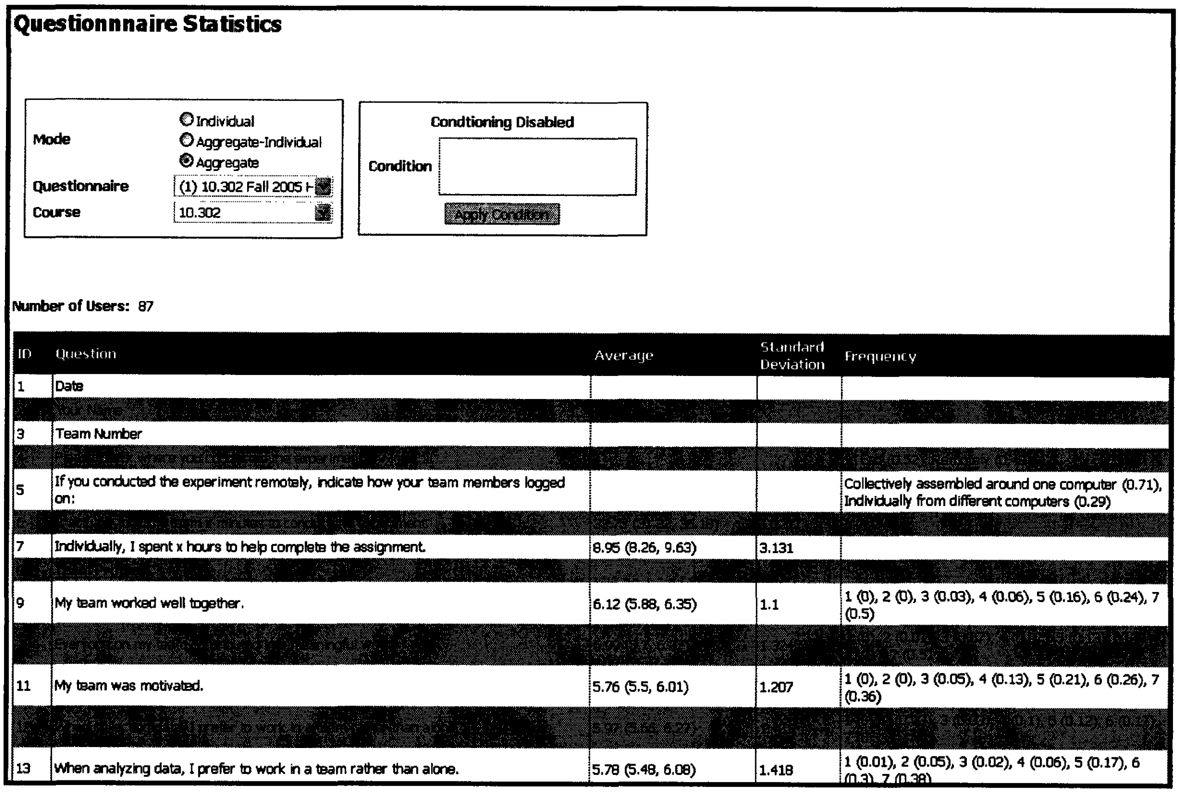


Figure 4-4: Questionnaire statistics interface in aggregate mode.

4.2.2 Conditioning

In aggregate-individual and aggregate modes, a "conditioning" panel is presented at the top of the questionnaire statistics interface. The conditioning panel allows specification of conditions that a user, or, more specifically, his questionnaire responses, must satisfy to be included in the aggregate.

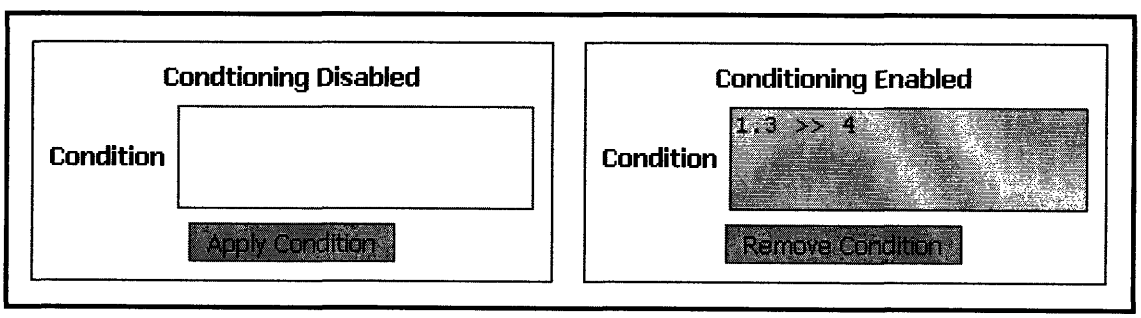


Figure 4-5: Conditioning panel with conditioning disabled (left) and conditioning enabled (right).

While the text field is empty and until the "Apply Condition" button is pressed, no condition is placed on users. In this state, as shown in Figure 4-5, the heading at the top of the conditioning panel reads "Conditioning Disabled". Once the button is pressed, the specified condition is applied. In this conditioning enabled state, as shown in Figure 4-5, the label of the button changes to read "Removes Condition" and the label of the conditioning panel changes to read "Conditioning Enabled" (in green text). In addition, the number of users listed at the top of the interface changes to reflect the amount of responders to the selected questionnaire that meet the applied condition. Pressing the button in this state causes the applied condition to be removed.

4.2.2.1 Condition Syntax

A condition clause consists of a questionnaire item, a comparison symbol, and a value, as specified below:

questionnaire-id.qitem-id comparison-symbol value

As indicated above, the specification of a questionnaire item consists of a combination of two items: a *questionnaire-id* specifier, which is the ID of the questionnaire that contains the relevant instance of the questionnaire item, and a *qitem-id* specifier, which is the ID of the relevant questionnaire item. As is visible in Figure 4-4, the ID of a questionnaire is listed in parenthesis next to its title in the questionnaire dropdown list. Note that the inclusion of the questionnaire ID in the questionnaire item specifier allows the set of user responses used for a questionnaire to be based on the responses users provided to a different questionnaire.)

Any of six comparison symbols may be used for the *comparison-symbol* specifier: `<<` (less than), `<=` (less than or equal), `>>` (greater than), `>=` (greater than or equal), `==` (equal), and `!=` (not equal). The comparison symbol denotes the type of comparison to be made between a user response to the specified questionnaire item and the *value* specifier. In addition, while any of the comparison symbols may be used with questionnaire items that have a numeric-valued response, only `==` and `!=` comparison symbols make sense for use with questionnaire items that have text-valued responses.

Finally, The *value* specifier may be any text or numeric value.

The following example specifies the condition that *the response of a user to questionnaire item 3 for questionnaire 1 has a value that is greater than or equal to 4:*

```
1.3 >> 4
```

More complex conditions may be created by stringing together clauses with logical AND (`&`) and OR (`|`) conjunction symbols. Parenthesis may also be used for grouping. For example, the following condition specifies that *the responses of a user to questionnaire items 5 and 10 of questionnaire 2 have the values "yes" and "no," respectively.*

```
(2.5 == yes) & (2.10 == no)
```

4.3 Summary of Questionnaire Study

4.3.1 Questionnaire Study Overview

In the fall of 2005, chemical engineering students performed two experiments as part of the lecture class Transport Processes (10.302): the Radial Heat Conduction Experiment (HeatCon) and the Flat Plate Heat Exchanger Experiment (HeatEx). For the experiments, students were grouped into two different sets in order to compare the experiences of individuals performing experiments online with those of individuals performing experiments in the facilities housing experimental equipment. Students were randomly assigned to one of 28 teams that were 3 or 4 students in size. Each of the teams was randomly assigned to be either Type A (15 teams) or Type B (13 teams). Type A teams were instructed to perform the initial experiment (HeatCon) remotely via a web browser and to perform the second experiment (HeatEx) in the laboratory facilities housing the flat plate heat exchanger. Conversely, Type B teams were instructed to perform the initial experiment (HeatCon) in the laboratory facilities housing the radial heat conduction equipment and to perform the second experiment (HeatEx) remotely via a web browser.

Irrespective of whether teams were performing an experiment remotely or in lab, Virtual Instruments were used to interact with laboratory equipment and to collect sensor data. However, when performing an experiment in lab, teams worked at a single computer console which ran the relevant Virtual Instrument. Students were able to freely view, hear and otherwise examine the laboratory equipment being used. When performing an experiment remotely, teams had the choice of either working collectively around a single computer console (not located in the laboratory facility) or working individually from separate computer consoles (also not located in the laboratory facility). A teaching assistant was always available in the laboratory to assist students while they performed experiments.

After completing each of the assignments, students were requested to complete a questionnaire about their experience. While completion of these questionnaires was not mandatory, students were offered bonus points as an incentive for them to complete them. This resulted in a nearly 100% response rate with 87 and 84 out of 88 students completing the questionnaires for the HeatCon and HeatEx experiments, respectively.

The questionnaires include a collection of Likert Scale items that profile seven areas of user experience: team profile, usability, understanding, learning objectives, learning behavior, learning experience, and overall experience. Each item asks a respondent to rate on a seven-point scale how much they agree with a statement: a rating of "1" indicates strong disagreement and a rating of "7" indicates strong agreement.

Six scales were developed from the questionnaire items: Team Profile, Understanding, Learning Objectives, Learning Behavior While Running Experiment, Learning Behavior While Analyzing Data, and Learning Experience. The Team Profile Scale consists of items that measure how well students worked together in their teams. The Understanding Scale contains items that measure whether an experiment affected student understanding of certain experiment-specific concepts. The Learning

Objectives Scale measures how well an experiment achieved certain experiment-specific educational objectives. Unlike the other four scales, the Understanding Scale and Learning Objectives Scale consist of items that differ between experiment questionnaires as they measure experiment-specific experience features. The Learning Behavior While Running Experiment Scale consists of items that address the level of conceptualization or deep learning that occurred as students gathered data during the experiment. The Learning Behavior While Analyzing Data Scale consists of items that address the level of conceptualization or deep learning that occurred as students analyzed data after the experiment. These latter two scales seek to measures whether students were forced to apply mental operations such as visualizing how equipment works and thinking about how concepts learned from the experiment can be applied to other situations. The Learning Experience Scale contains items that measure how positive students found their experience to be.

Scales have not been developed for the Usability and Overall Experience questionnaire items. The Usability section consists of survey items that measure how easy to use different aspects of the experiment interface are. The Overall Experience section consists of questionnaire items that address general aspects of the user experience. In particular, this section contains items that address the mode of experimentation (online or in lab) that students prefer.

4.3.2 Questionnaire Study Results

Students overall agreed that the two experiments were positive experiences. The experiments achieved their desired educational objectives and increased student understanding of concepts related to heat conduction and heat exchange processes. In performing the experiments, students indicated that they were forced to employ higher-level thinking. They noted that they worked well with their team members. And, while students thought that the experiments were tedious and lacked excitement, they did agree that the experiments were stimulating, interesting and challenging.

There is little difference in the feelings of students on most aspects of the two experiments. However, the Understanding Scale and Learning Experience Scale means for the Flat Plate Heat Exchanger Experiment are higher than those means for the Radial Heat Conduction Experiment. Students reported that they had a slightly better learning experience, one that was less tedious, less frustrating, and more enjoyable, while conducting the Flat Plate Heat Exchanger Experiment. Comments provided by students indicate that this experiment was more straightforward and that the amount of work necessary to complete the assignment was better suited to the amount of time provide to complete it. Students also commented that they were able to gain a better understanding of concepts presented in this experiment.

The questionnaires seem to indicate that mode of experimentation (online, in lab) did not have much, if any, affect on learning experience. When students are broken out by team type (i.e. mode of experimentation), there are no significant differences in scale means for the Radial Heat Conduction Experiment questionnaire. For the Flat Plate Heat Exchanger Experiment questionnaire, the only significant difference is in the Team Profile Scale means: while Type A students, who performed the experiment in lab, and

Type B students, who performed the experiment remotely, both reported a very positive view of their team experience, the view of Type B students was less positive.

The experiment interfaces elicited positive responses from students. They reported that the Virtual Instruments clearly and coherently displayed information. The graphical presentation of data helped students to reason about the physical processes taking place in experiments. Overall, the Virtual Instruments enhanced the learning experience. Similarly, students found the chat facility to be useful when performing an experiment remotely via the web; it was particularly effective in allowing students to communicate with the teaching assistant.

Patterns found in the preferences of students for modes of experimentation were unexpected. While, when taken as a single group, there was no significant difference in the ratings of the two modes of experimentation by students, interesting patterns emerged when ratings were looked at among Type A and Type B students separately. The survey data seems to indicate that the initial mode to which students were exposed is a powerful influencing force. Type A students, who performed the first experiment remotely, initially rated online experimentation above in lab experimentation. Similarly, Type B students, who performed the first experiment in lab, initially rated in lab experimentation above online experimentation. After performing the second experiment, for which they switched modes of experimentation, Type A students maintained their preference for online experimentation over in lab experimentation. The Type B student mean rating for in lab experimentation was higher than the Type B student mean rating for online experimentation, but given the high variance in responses, the difference is not significant. A potential influencing factor for this is the existence of an additional component of the Radial Heat Conduction Experiment for those performing the experiment in lab (i.e. type B students). The existence of this extra component may have caused type B students to rate in lab experimentation higher and online experimentation lower than they would have if the in lab version of the Radial Heat Conduction Experiment had not included an extra component.

The results presented above are taken from a questionnaire study completed as part of this thesis. A draft of the paper, as well as the two questionnaires used in the study, can be found in the appendix.

5 Improvements to Website and Experiment Presentation

5.1 Integration of Camera Feed

To improve the overall experiment interface, the feed from the web camera in the laboratory was embedded in the experiment interface pages. Comparing Figure 2-2 with Figure 5-1, the addition of video (and audio) to the experiment interface page is apparent. With this change, it is no longer necessary for users performing remote experiments via the iLab Heat Transfer Project site to have a separate media player installed in order to access the feed from the laboratory camera. Moreover, the need to switch between the experiment interface page and the feed while performing an experiment has been removed.

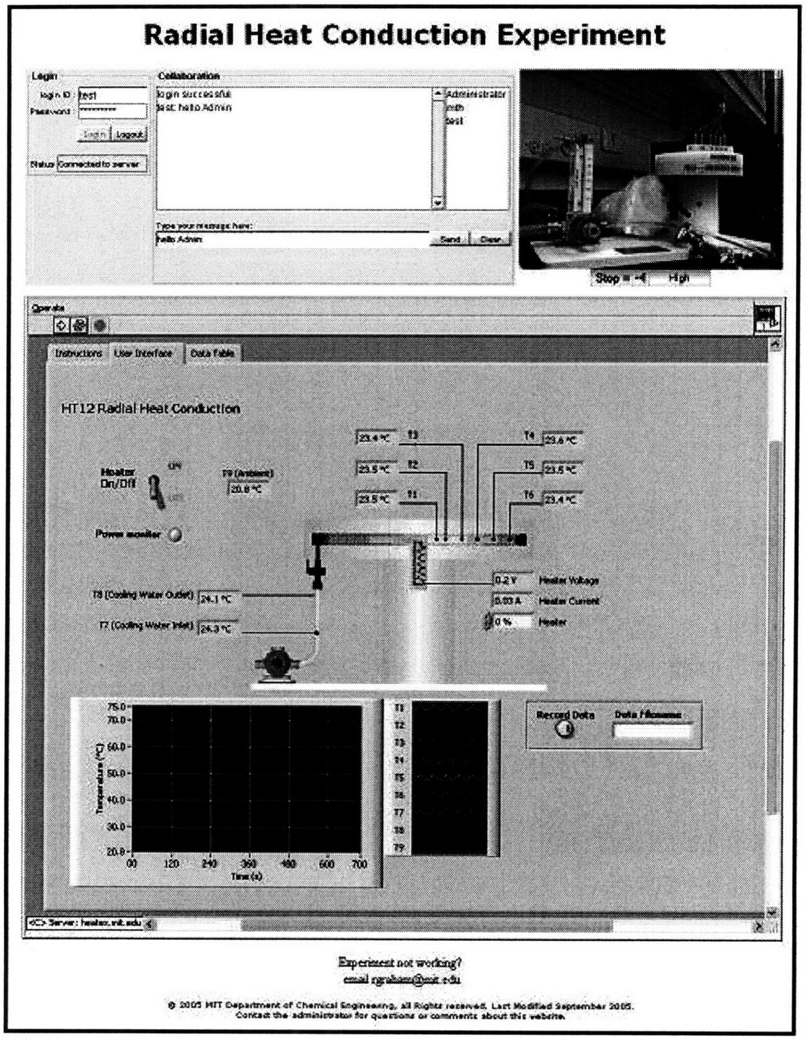


Figure 5-1: Experiment interface page with integrated web camera feed (for the Radial Heat Conduction Experiment).

Integration of the web camera feed into the experiment interface pages required that new software be installed on the server. The Webcam Tracker Live application, which was being used for the purposes of broadcasting the web camera feed over the web, was replaced with software from the company Clipstream. The new software, Clipstream Live, made it possible to embed a Java applet on the experiment interface pages that displays the stream from the laboratory web camera. In addition, as it is simply a Java applet, viewing of the web camera stream requires only that the browser of the viewing user have a recent Java browser plugin, which is commonly already installed. The code added to the experiment interface pages to embed the stream from the web camera is provided below in Figure 5-2. As is visible from the code (see the `codebase` attribute of the `Applet` tag), the Clipstream software broadcasts the web camera stream on port 83 of the server.

```
<Applet MayScript codebase="http://heatex.mit.edu:83/"
 cabbase=clipstreamlive.cab  archive=clipstreamlive.zip
code=clipstreamlive.class
 alt=ClipstreamLive  name=clipstreamlive
 width=320  height=260>
<param name='AutoBitrate' value='true'>
<param name="VideoURL1"       value="Low,0,/live044.vcs">
<param name="VideoURL2"       value="High,555,/live256.vcs">
<param name="AutoPlay"  value="True">
<param name="VideoBufferSize"       value="5">
<param name="BackgroundColor"       value="#FFFFFF">
<param name="TextColor"       value="#000000">
<param name="SeekEnable"      value="false">
<param name="PanelEnable"     value="True">
<param name="PanelImagesURL"  value="buttons.gif">
<param name="PanelLayout"     value="PMC">
<param name="PanelImageWidth"       value="51,1,52,1,1,1,1,20,75">
<param name="PanelFlash"      value="2">
<param name="PanelPopup"      value="False">
<param name="PanelPosition"   value="Bottom">
<param name="VideoTitleImageURL"    value="title.gif">
<param name="VideoEdgeColor"  value="#FFFFFF"><br>
</Applet>
```

Figure 5-2: Code added to experiment interface pages to embed stream from web camera.

A problem was encountered in using the Clipstream software, however, that required a hardware change be made to the server. Both the web camera and Armfield service units communicate with the server by way of the USB. Unfortunately, having the web camera (with Clipstream) and an Armfield service unit connected to the server at once required more bandwidth than was available by way of the USB 1.0 PCI adapter card that was originally installed in the server: Clipstream software broadcasts a larger image at a higher resolution than the Webcam Tracker Live software does. Therefore, it was necessary to replace the USB 1.0 PCI adapter card with a USB 2.0 PCI adapter card to meet the bandwidth demands of the equipment. Figure 5-3 shows an image of the replacement PCI adapter card. With this hardware upgrade made, both the web camera and an Armfield service unit can simultaneously communicate via the server USB.

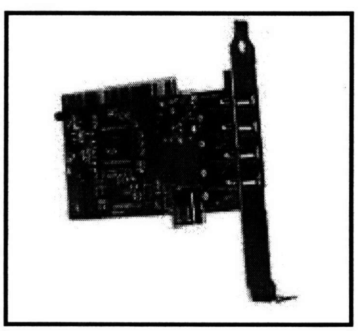


Figure 5-3: Image of Kingwin USB 2.0 PCI adapter card (Model No.: U2PCI-5).

5.2 Modification of Virtual Instruments

Several modifications were made to all seven of the Virtual Instruments in the course of completing the work of this thesis. Most of these modifications were minor. The texts of the Instructions tabs of the VIs were edited to improve the clarity of the instructions presented to users. The layouts of the controls and indicators on the Main Interface tabs of VIs were modified to reduce the size of the interfaces. The data tables and recorded data streams for VIs were augmented to include in each set of data readings the time at which the data readings are taken. In addition, the shared code module that is responsible for providing the data record functionality for all the VIs was modified: the formatting of data file contents—in particular, the formatting of data column headers—was improved.

In addition to these minor changes, new features were added to Virtual Instruments for the Radial Heat Conduction Experiment and the Radiation with Convection Experiment. These changes are detailed in the following sections.

5.2.1 Radial Heat Conduction Experiment

Three new thermocouples were added to the HT12 radial heat conduction accessory unit. As shown in Figure 5-5, a tube connects to the periphery of the main disk of the radial heat conduction accessory. This tube allows the inflow of cold water to cool the disk. A thermocouple, designated T7, has been added to measure the temperature of the water flowing in through this tube. Another tube, obscured in Figure 5-5, allows the outflow of the cooling water. A thermocouple, designated T8, has been added to measure the temperature of the water flowing out through this tube. Additionally, a sensor, designated T9, has been added to measure the ambient temperature of the surroundings of the equipment.

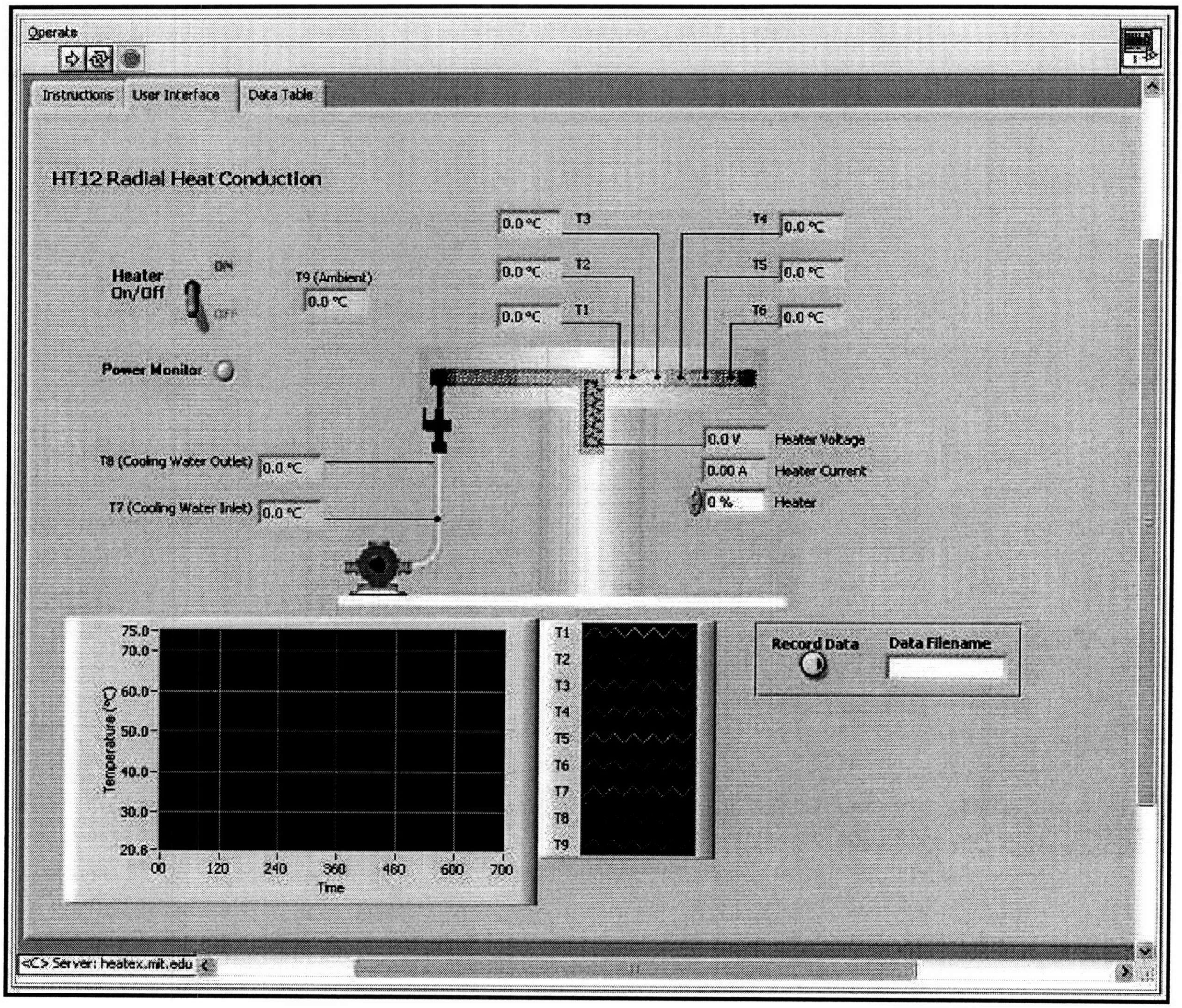


Figure 5-4: Virtual instrument for Radial Heat Conduction Experiment with User Interface tab selected.

The Virtual Instrument for the Radial Heat Conduction Experiment was updated to accommodate the addition of these new sensors. As seen in Figure 5-4, the Main Interface tab of the VI was augmented with indicators for the three sensors: T7 (Cooling Water Inlet), T8 (Cooling Water Outlet), and T9 (Ambient). In addition, with reference to the graph key, it can be seen that the graph has been updated to chart values of sensors T7, T8, and T9. Similarly, the data table (see Figure 5-6) and the recorded data stream were updated to include the values of the new sensors.

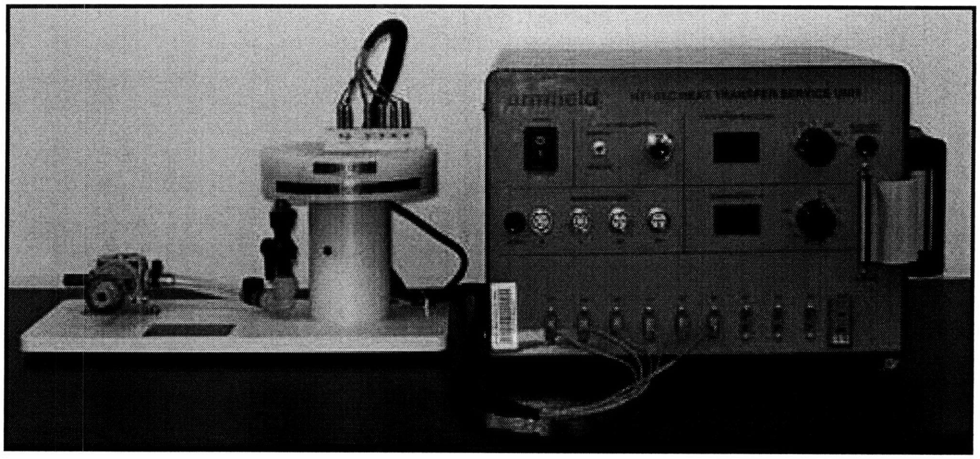


Figure 5-5: HT12 radial heat conduction accessory connected to HT10XC service unit.

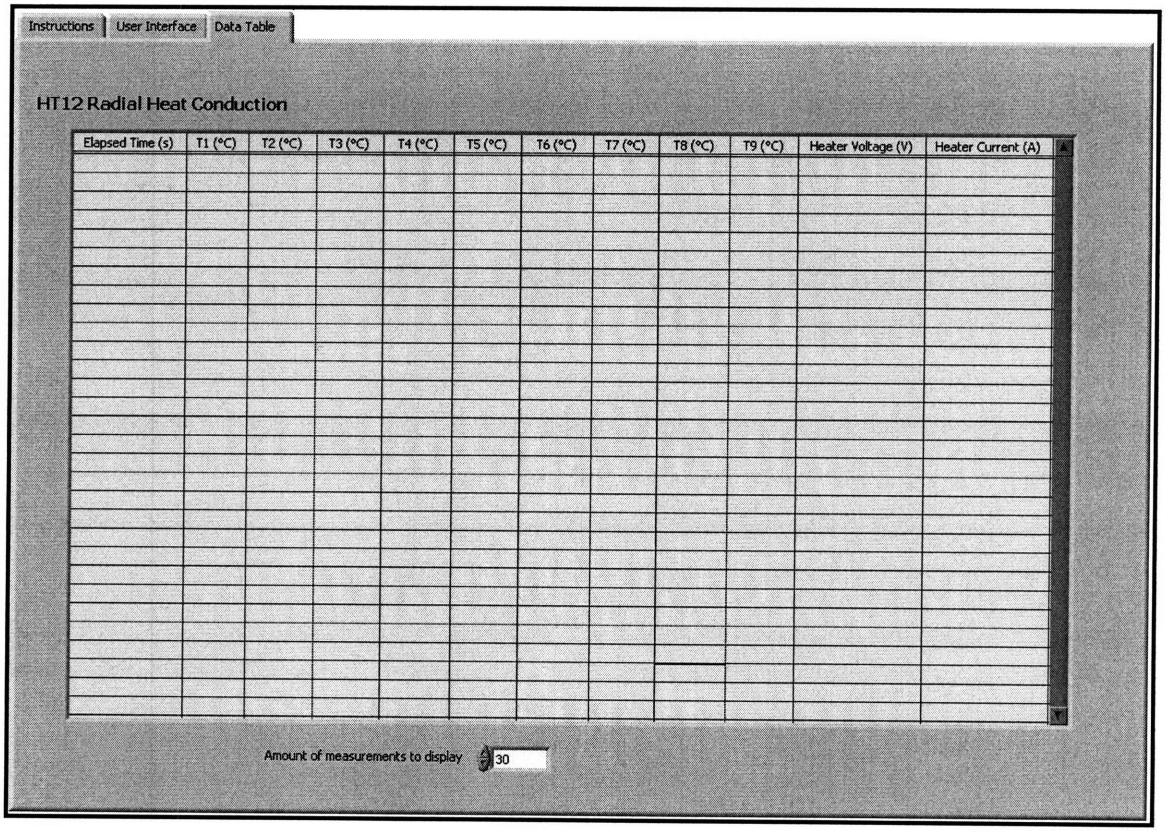


Figure 5-6: Virtual instrument for Radial Heat Conduction Experiment with Data Table tab selected.

5.2.2 Radiation with Convection Experiment

As pictured in Figure 5-7, the HT14 combined convection and radiation accessory consists of a centrifugal fan and a long cylindrical outlet duct that sits on top of the fan. Mounted at the top of the vertical outlet duct is a heated horizontal cylinder. A thermocouple attached to the wall of the heated cylinder, designated T10 (see Figure

5-8), provides a measurement of the surface temperature from which heat transfer calculations can be performed. Furthermore, the heated cylinder can be rotated to vary the position of the thermocouple and allow a determination of the temperature distribution around the surface of the cylinder.

The User Interface tab of the VI for the Radiation with Convection Experiment was updated to add the position of the heated cylinder thermocouple to the data collected. The HT14 combined convection and radiation accessory has no means of detecting or reporting the current position of the heat cylinder thermocouple, so an input field, labeled Cylinder Angle (see Figure 5-8), was added to the interface to allow the user to specify the position. The "cylinder angle" represents the angle, ranging from 0° to 360°, that the heated cylinder thermocouple (T10) makes with the vertical duct. The Armfield manual for the HT14 accessory defines an angle system that is used in the specification of the cylinder angle [1].

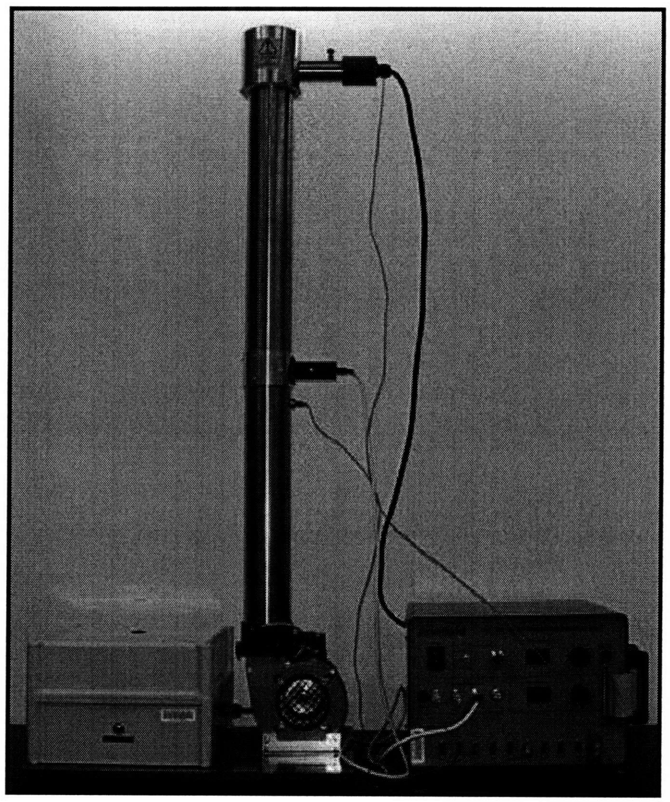


Figure 5-7: HT14 combined convection and radiation accessory connected to HT10XC service unit.

In addition to adding an input control through which a user can specify the current cylinder angle, the Data Table tab was updated to display the current cylinder angle in each set of data readings. Similarly, the recorded data stream was updated to include the cylinder angle with each set of data readings.

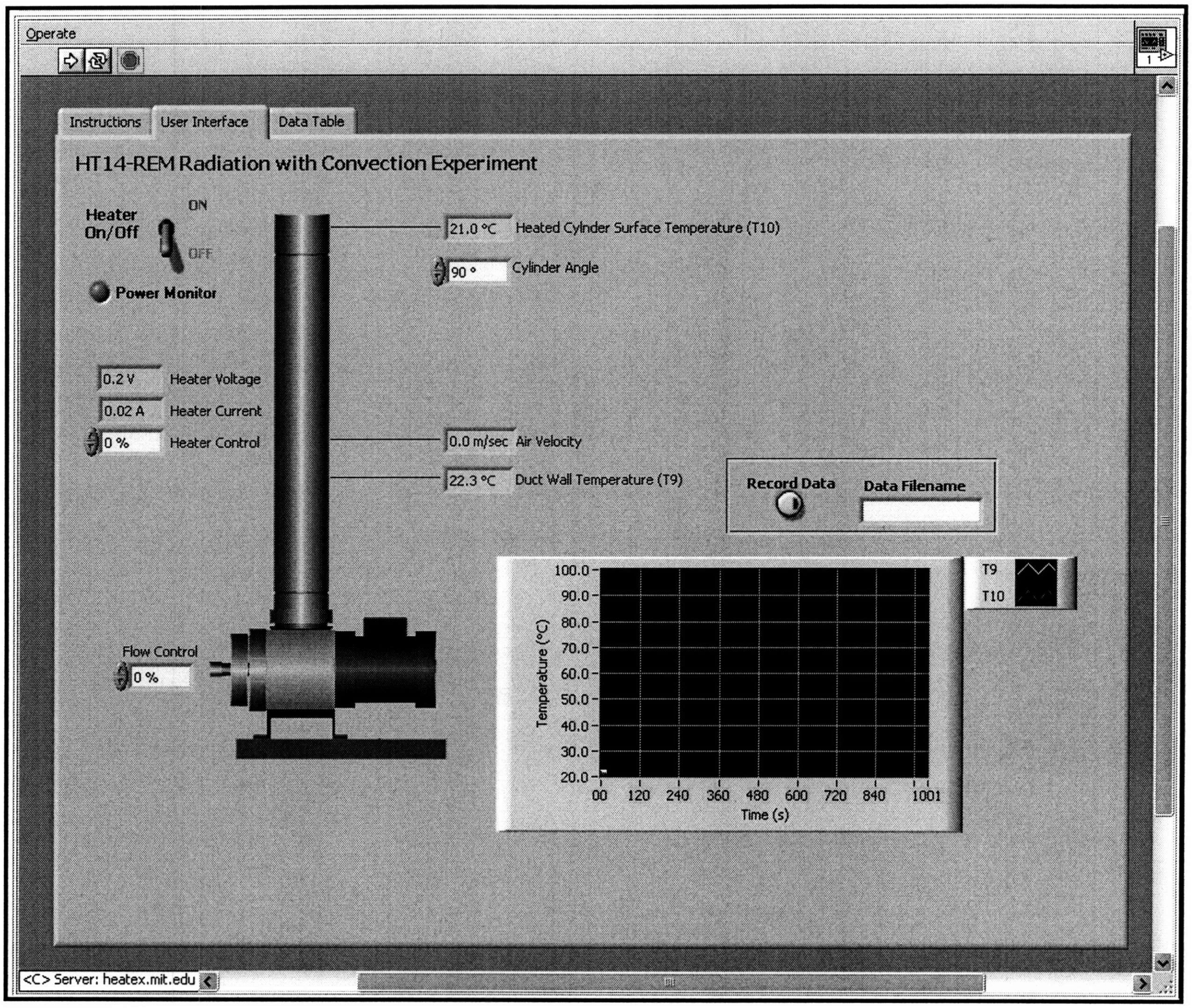


Figure 5-8: Virtual Instrument for Radiation with Convection Experiment with User Interface tab selected.

6 Conclusion and Future Work

6.1 Deliverables

Several deliverables have been developed over the course of the work of this thesis. A summary of the features developed for the iLab Heat Transfer Project is provided below:

- Developed an interface for the website that allows instructors to post documents for use with their courses. The feature also allows the management of documents once they have been posted to the website.

- Developed an interface for the website that allows instructors to manage the teams and sessions of their courses. The interface also provides a means of programmatically archiving the content of a course session.

- Developed an interface for the website that provides instructors with the ability to view and edit the registration information for their students.

- Extended the announcement interface of the website with the ability to delete announcements.

- Developed an interface for the website that provides administrators with control over the advertisement of currently active experiments.

- Developed a system for storing the contents of questionnaires and user responses to questionnaires in the database backend of the website. An interface for the website was also developed that provides several means to view and analyze questionnaire responses.

- Integrated into the interfaces of web experiments an audio and video feed of the laboratory equipment. The LabVIEW Virtual Instruments that compose the experiment interfaces were updated to add additional controls and sensors.

6.2 Future Work

While many improvements were made to the iLab Heat Transfer Project site as part of this thesis, there still exist areas for further work.

- An Interactive Architecture is being developed for the iLab Initiative that will allow the iLab Heat Transfer Project to be integrated into a larger system of web-based laboratory experiments. The system, among other things, allows universities to trade time on their own web-based equipment for time on equipment of other universities.

  While efforts were made in the past year to integrate the iLab Heat Transfer Project with this system, the Interactive Architecture that would allow this remains under development. This work should be completed in the following months, allowing the integration to finally take place.

- Data from questionnaires completed by students of past sessions of courses that have worked with the project is available in various forms. It would be beneficial to add this data to the current database of responses for further analysis.

- Currently, there is no means of limiting the privileges of instructors so that they may only edit items associated with their courses. Implementing this feature would ensure the integrity of course data against accidental modification by other instructors.

References

[1] Armfield Limited. "Instruction Manual: HT14C—Computer Compatible Combined Convection and Radiation". Issue 2. March 2006.

[2] iLab Heat Transfer Project Website. <http://heatex.mit.edu>, July 2006.

[3] Saylor, David P. "Extensions and Enhancements to the iLab Heat Transfer Project Site". M.Eng. Thesis. MIT, 2005.

Appendix

A Survey Study of the iLab Heat Transfer Project User Experience

Abstract
The iLab Heat Transfer Project was developed to provide a collection of web-based, remotely controlled experiments that assist in the teaching heat transfer concepts. By way of the experiment interfaces created for the project, students are able to interact with laboratory equipment as if they had direct physical access to it. The experiment interfaces also allow students to record data from sensors available on the equipment. This paper describes a survey study of the experiences of students taking a heat and mass transfer course; students performed two experiments provided by the iLab Heat Transfer Project. The experiments were performed in either of two modes: remotely via the web or in the laboratory facilities containing the experimental equipment. Results from post-experiment surveys suggest that the experiments provided a positive learning experience and increased student understanding of heat transfer concepts. Students indicated that the experiment interfaces were well designed and helped them to reason about the physical processes taking place in the experiments. Moreover, the mode of experimentation had no apparent affect on the learning experience of students.

Introduction
The iLab Heat Transfer Project was initiated in 2000 within the MIT Department of Chemical Engineering to develop, test, and evaluate web-based, remotely controlled experiments that are useful in teaching concepts of heat transfer processes [1]. While the initial focus of this project was on heat exchange, particularly the analysis of performance and design of optimum process controllers, its focus has grown to include experiments on heat conduction, convection, and radiation processes [1]. A collection of graphical user interfaces (see Figure 1), known as Virtual Instruments, has been developed (using the LabVIEW programming language) that allows students to control laboratory equipment used in heat transfer experiments.

This paper examines the experience of students who worked with the iLab Heat Transfer Project two complete two laboratory assignments on heat conduction and heat exchange processes. For the initial assignment, students were required to measure the temperature distribution along a heated radial disk and compare experimental results with the temperature profile predicted by theoretical analysis [2]. For the subsequent assignment, students were required to collect data from a flat plat heat exchanger in order to characterize its operation [3]. Students were divided into two sets: one set of students performed the first experiment online and performed the second experiment in lab, while the other set of students performed the first experiment in lab and performed the second experiment online.

Students were asked to complete surveys following their completion of each assignment. The items included on the survey sought to provide insight into different aspects of the user experience provided the project. How well did teams of students work together? What level of learning occurred as students gathered data during experimentation and as students analyzed data after experimentation? How well did the experience contribute to understanding of certain experiment-specific concepts? How well did the experiments achieve certain experiment-specific educational objectives? How usable was the experiment interface? How positive was the overall lab experience? Finally, in addition to these matters, it was important to examine how the mode in which students performed an experiment, either online or in lab, affected each these aspects of their experience.

Method

In the fall of 2005, chemical engineering students at the Massachusetts Institute of Technology performed two experiments as part of the lecture class Transport Processes (10.302), which focused on the principles heat and mass transfer. These experiments, one concerning radial heat conduction and another concerning a flat plate heat exchanger, were performed using LabVIEW Virtual Instruments designed for the iLab Heat Transfer Project. Figure 1 and Figure 2 provide screenshots of the Virtual Instruments used for the Radial Heat Conduction Experiment (HeatCon) and the Flat Plate Heat Exchanger Experiment (HeatEx), respectively.

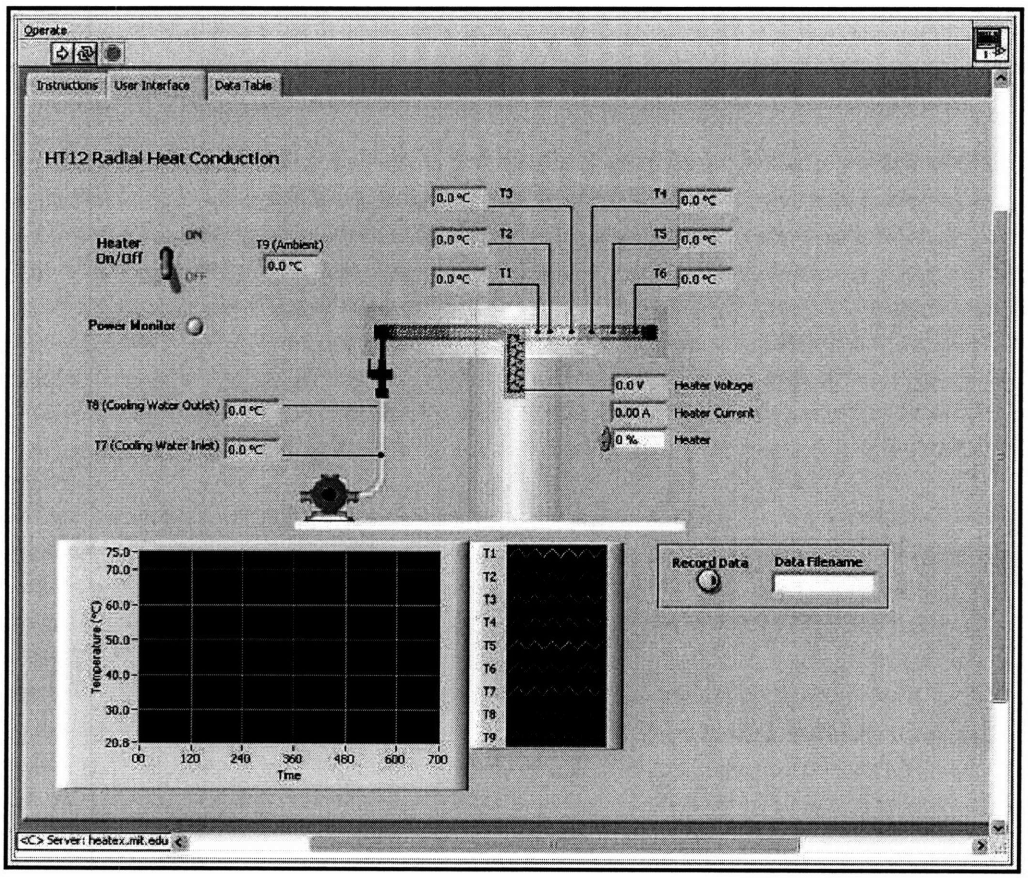


Figure 1: LabVIEW Virtual Instrument for Radial Heat Conduction Experiment.

For the experiments, students were grouped into two different sets in order to compare the experiences of individuals performing experiments online with those of individuals performing experiments in the facilities housing experimental equipment. Students were randomly assigned to one of 28 teams that were 3 or 4 students in size. Each of the teams was randomly assigned to be either Type A (15 teams) or Type B (13 teams). Type A teams were instructed to perform the initial experiment (HeatCon) remotely via a web browser and to perform the second experiment (HeatEx) in the laboratory facilities housing the flat plate heat exchanger (pictured in Figure 3). Conversely, Type B teams were instructed to perform the initial experiment (HeatCon) in the laboratory facilities housing the radial heat conduction equipment (pictured in Figure 4) and to perform the second experiment (HeatEx) remotely via a web browser. Both of the aforementioned pieces of lab equipment were housed in the same laboratory facilities.

Irrespective of whether teams were performing an experiment remotely or in lab, Virtual Instruments, pictured in Figure 1 and Figure 2, were used to interact with laboratory equipment and to collect sensor data. However, when performing an experiment in lab, teams worked at a single computer console which ran the relevant Virtual Instrument. Students were able to freely view, hear and otherwise examine the laboratory equipment being used. A teaching assistant was available in the laboratory to assist students while they performed experiments.

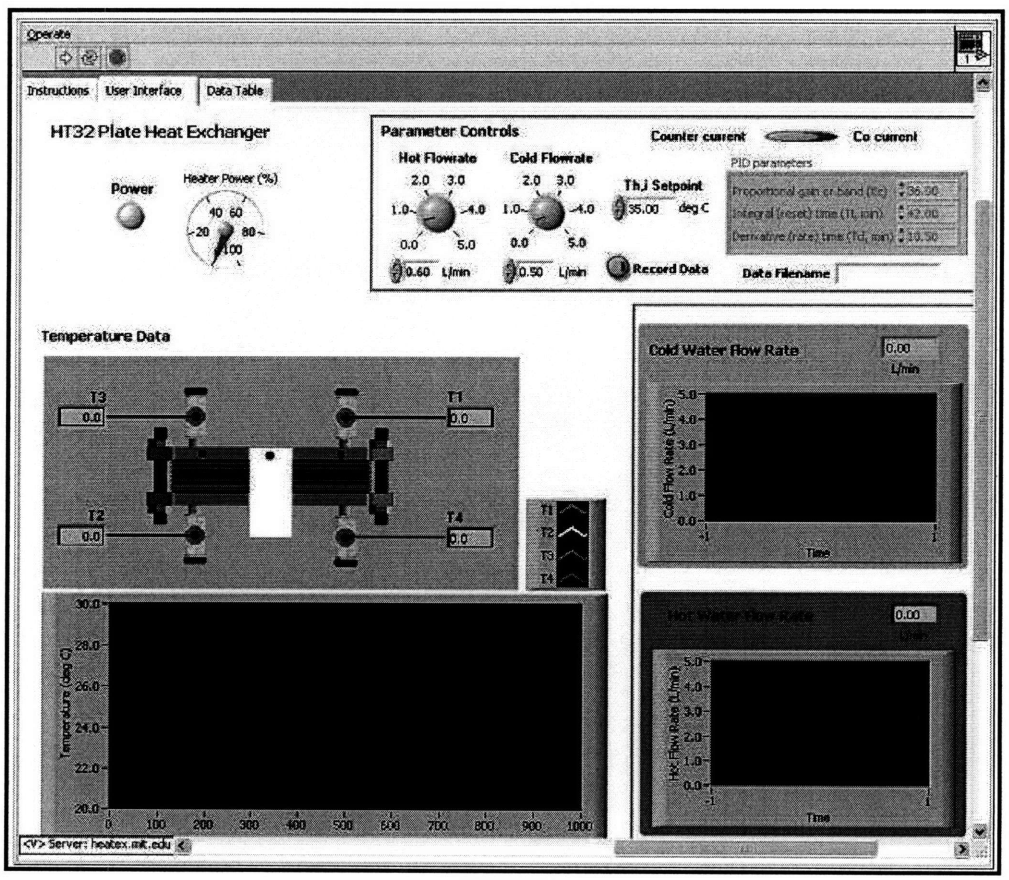


Figure 2: LabVIEW Virtual Instrument for Flat Plate Heat Exchanger Experiment.

When performing an experiment remotely, teams had the choice of either working collectively around a single computer console (not located in the laboratory facility) or working individually from separate computer consoles (also not located in the laboratory facility). The webpage that presented students with the Virtual Instrument for an experiment also contained a chat application. The chat application allowed students to communicate with each other (if they were working from different computers) and/or to communicate with a teaching assistant in the lab. For those teams that chose to collaborate from separate computers, the chat facility was crucial in allowing them to coordinate their activities. While all individuals are able to simultaneously view a Virtual Instrument, only one person can control it at a time. Thus, the chat facility was used to coordinate transfer of control of the Virtual Instrument between team members. The webpage that presented students with the Virtual Instrument and chat facility also provided a video and audio feed of the laboratory equipment being used for the experiment (Figure 5).

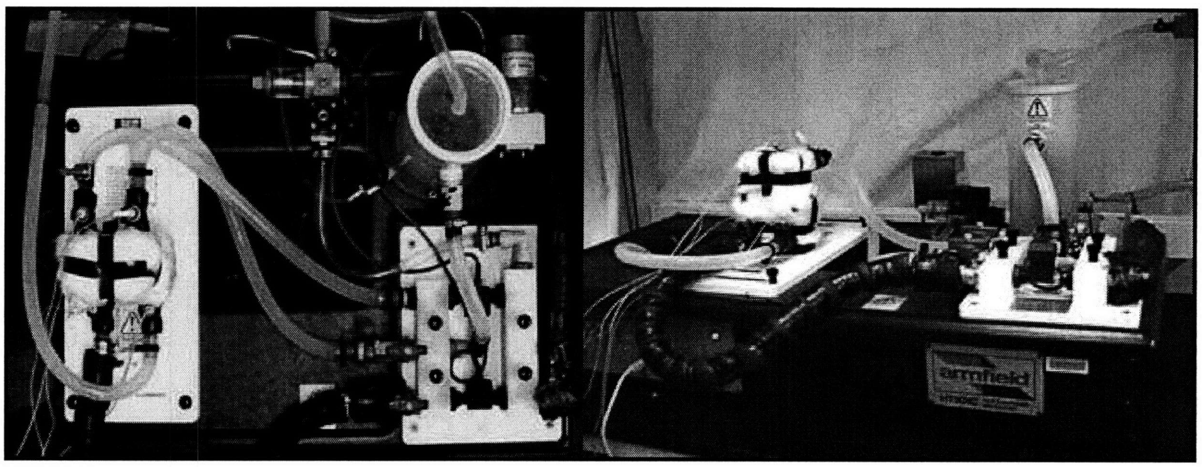


Figure 3: Armfield HT32 Flat Plate Heat Exchanger viewed from above (left) and from side (right).

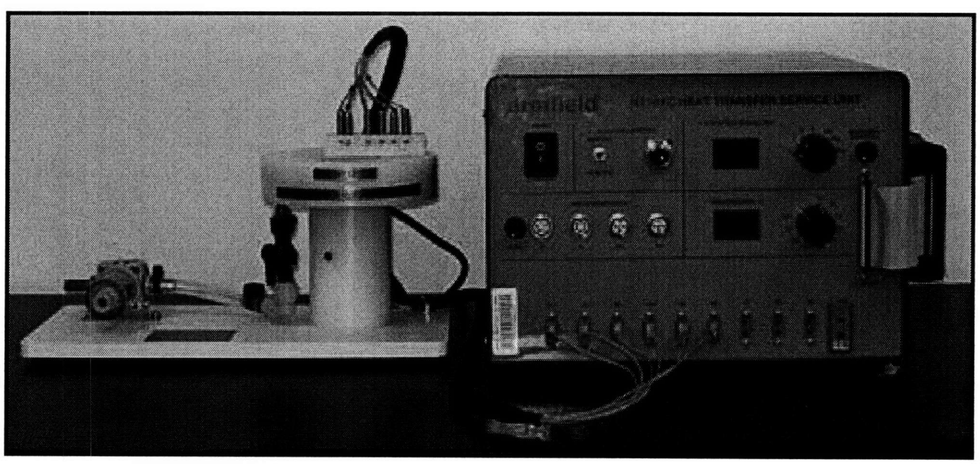


Figure 4: Armfield HT12 Radial Heat Conduction Accessory connected to Armfield HT10XC service unit.

After completing each of the assignments, students were requested to complete a survey about their experience. While completion of these surveys was not mandatory, students were offered bonus points as an incentive for them to complete them. This resulted in a nearly 100% response rate with 87 and 84 out of 88 students completing the surveys for the HeatCon and HeatEx experiments, respectively.

The surveys include a collection of Likert Scale items that profile seven areas of user experience: team profile, usability, understanding, learning objectives, learning behavior, learning experience, and overall experience. Each item asks a respondent to rate on a seven-point scale how much they agree with a statement: a rating of “1” indicates strong disagreement and a rating of “7” indicates strong agreement.

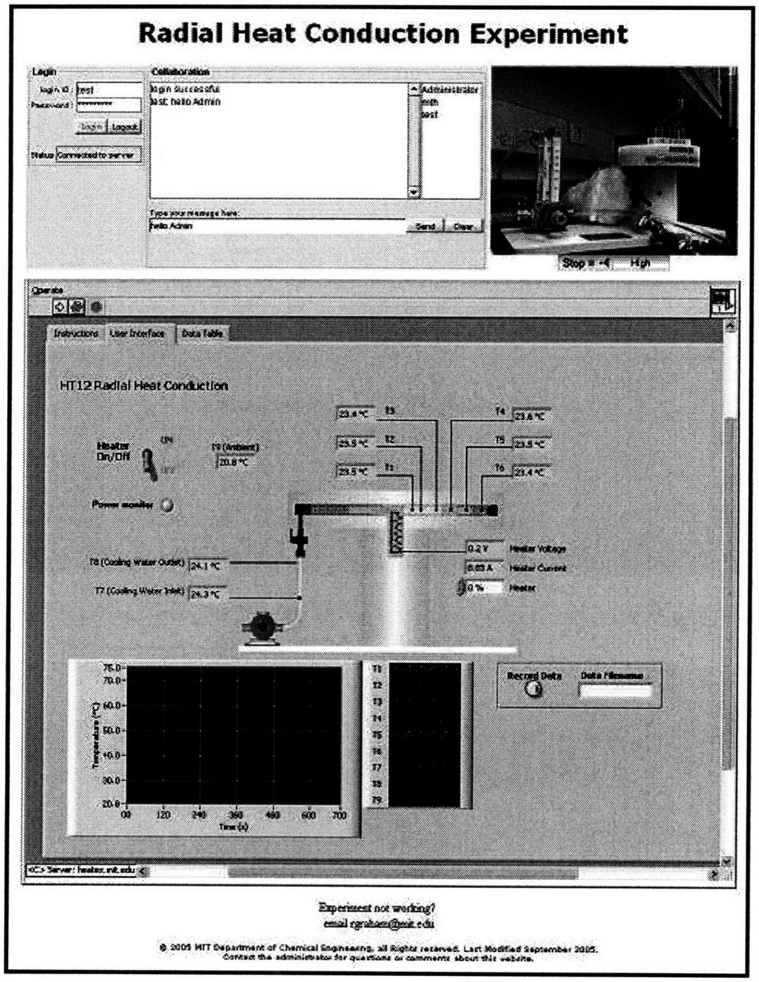


Figure 5: Experiment interface page with chat facility, video feed, and Virtual Instrument (for Radial Heat Conduction Experiment).

Six scales were developed from the survey items: Team Profile, Understanding, Learning Objectives, Learning Behavior While Running Experiment, Learning Behavior While Analyzing Data, and Learning Experience. The Team Profile Scale consists of items that measure how well students worked together in their teams. The

Understanding Scale contains items that measure whether an experiment affected student understanding of certain experiment-specific concepts. The Learning Objectives Scale measures how well an experiment achieved certain experiment-specific educational objectives. Unlike the other four scales, the Understanding Scale and Learning Objectives Scale consist of items that differ between experiment surveys as they measure experiment-specific experience features. The Learning Behavior While Running Experiment Scale consists of items that address the level of conceptualization or deep learning that occurred as students gathered data during the experiment. The Learning Behavior While Analyzing Data Scale consists of items that address the level of conceptualization or deep learning that occurred as students analyzed data after the experiment. These latter two scales seek to measures whether students were forced to apply mental operations such as visualizing how equipment works and thinking about how concepts learned from the experiment can be applied to other situations. The Learning Experience Scale contains items that measure how positive students found their experience to be.

Scales have not been developed for the Usability and Overall Experience survey items. The Usability section consists of survey items that measure how easy to use different aspects of the experiment interface are. The Overall Experience section consists of survey items that address general aspects of the user experience. In particular, this section contains items that address the mode of experimentation (online or in lab) that students prefer.

Results

Table 1 present scale data for each experiment survey. Coefficient alphas, which are all greater than .75, are high enough to provide stable measures. Moreover, all scale means are positive (i.e. above 4.00), which indicates that students on average reported positive experiences for each aspect of the experiment that was measured. Comparing scales, by way of paired two-tailed *t*-tests, there are no significant differences (α=0.05) in scale means between the two experiments except for the Understanding Scale and Learning Experience Scale. Students expressed a slightly better understanding of concepts (5.13, 5.37) and a slightly better learning experience (4.08, 4.37) for the second experiment (HeatEx). Comments supplied by students support this finding: students felt they had a better understanding of relevant concepts and had a more positive experience for the HeatEx experiment compared to the HeatCon experiment.

> "It was alot less stressful than the first assignment. I enjoyed this one more, probably because I have a better grasp of the concepts covered in this experiment."

> "The assignment was challenging but doable, so I was able to actually understand what I was doing/why I was doing it/what it meant.

Students believed they worked extremely well with their team members as indicated the Team Profile Scale means of 5.95 and 5.88. As Table 2 indicates, students strongly believed that all their team members contributed in a meaningful way (5.99, 5.82) and that their team was motivated (5.76, 5.81). Moreover, they strongly agreed that they preferred working in a team (to working individually) when collecting data (5.97, 5.75) and analyzing data (5.78, 5.58).

As the Learning Behavior While Running Experiment Scale means of 4.80 and 4.92 express, students believed they were required to exercise higher-level thinking and conceptualization while running experiments. They indicated that they visualized how conduction and heat exchange work (4.91, 4.79); formulated mental models of how heat conduction systems and heat exchangers work (4.71, 4.96); thought about how the lab experience related to previously learned material (5.17, 5.10); and thought about data as it was collected (5.14, 5.06). Students reported that, to a lesser degree, they thought about how concepts learned from the experiments might be applied to other situations (4.16, 4.59).

Scale	Experiment	Alpha*	Mean	SD*	n*
Team profile	HeatCon	0.88	5.95	1.09	86
	HeatEx		5.88	1.17	83
Understanding$	HeatCon		5.13	0.93	86
	HeatEx		5.37	1.00	83
Learning objectives$	HeatCon		5.21	0.90	83
	HeatEx		5.32	0.99	76
Learning behavior while running experiment	HeatCon		4.80	1.32	87
	HeatEx		4.92	1.12	81
Learning behavior while analyzing data	HeatCon		5.19	1.13	86
	HeatEx		5.32	1.12	83
Learning experience	HeatCon		4.08	1.12	84
	HeatEx		4.37	1.05	82

Table 1: Survey scales.
*** Alpha = coefficient alpha; SD = standard deviation; *n* = number of respondents included in calculations**
$ Scale items differ between experiment surveys

An increased amount of higher-level thinking and conceptualization appears to have occurred while students were analyzing data. This is indicated by the Learning Behavior While Analyzing Data Scale means of 5.19 and 5.32. Again, students reported that they visualized how conduction and heat exchange work (5.26, 5.37); formulated mental models of how heat conduction systems and heat exchangers work (5.21, 5.33); and thought about how the lab experience related to previously learned material (5.27, 5.43). Student responses also suggest that they applied concepts discussed in lecture/readings (5.51, 5.68); applied concepts in the theory section of the assignments (5.43, 5.52); and integrated concepts introduced at different times during the term (5.22, 5.08). To a lesser degree, students reported thinking about how concepts learned from the experiment might be applied to other situations (4.46, 4.74).

Selected Scale & Non-scale Items	Experiment	Mean	SD*	*n**
Team Profile				
* My team worked well together.	HeatCon	6.12	1.10	86
	HeatEx	5.96	1.14	84
* Everyone on my team contributed in a meaningful way.	HeatCon	5.99	1.32	86
	HeatEx	5.82	1.38	84
* My team was motivated.	HeatCon	5.76	1.21	86
	HeatEx	5.81	1.35	83
When collecting data, I prefer to work in a team rather than alone.	HeatCon	5.97	1.40	86
	HeatEx	5.75	1.38	84
When analyzing data, I prefer to work in a team rather than alone.	HeatCon	5.78	1.42	86
	HeatEx	5.58	1.46	84
Learning Behavior: Running Experiment				
* Visualizing how [conduction/heat exchanges] works.	HeatCon	4.91	1.56	87
	HeatEx	4.79	1.39	82
* Formulating a mental model of how a heat [conduction system/exchanger] works.	HeatCon	4.71	1.53	87
	HeatEx	4.96	1.33	82
* Thinking about how the lab experience relates to material previously learned.	HeatCon	5.17	1.53	87
	HeatEx	5.10	1.26	82
* Thinking about the data as they were being collected.	HeatCon	5.14	1.50	87
	HeatEx	5.06	1.36	82
* Thinking about how concepts learned from the experiment could be applied to other situations.	HeatCon	4.16	1.64	87
	HeatEx	4.59	1.41	81
Learning Behavior: Analyzing Data				
* Visualizing how [conduction/heat exchangers] work.	HeatCon	5.26	1.49	87
	HeatEx	5.37	1.35	84
* Applying concepts discussed in readings or lecture.	HeatCon	5.51	1.40	87
	HeatEx	5.68	1.18	84
* Applying concepts in the theory section of the assignment.	HeatCon	5.43	1.32	87
	HeatEx	5.52	1.23	84
* Formulating a mental model of how a heat [conduction system/exchanger] works.	HeatCon	5.21	1.29	87
	HeatEx	5.33	1.37	84
* Thinking about how the lab experience relates to material previously learned.	HeatCon	5.27	1.16	86
	HeatEx	5.43	1.31	83

* Thinking about how concepts learned from the experiment could be applied to other situations.	HeatCon	4.46	1.53	87
	HeatEx	4.74	1.51	84
* Integrating concepts introduced at different times during the term.	HeatCon	5.22	1.43	87
	HeatEx	5.08	1.49	84
Learning Experience				
* Meaningful	HeatCon	4.57	1.39	86
	HeatEx	5.04	1.36	84
* Enjoyable	HeatCon	3.68	1.46	85
	HeatEx	4.17	1.35	83
Stressful	HeatCon	5.39	1.44	85
	HeatEx	3.72	1.56	82
* Stimulating	HeatCon	4.28	1.39	85
	HeatEx	4.34	1.30	83
Tedious	HeatCon	5.21	1.57	85
	HeatEx	4.18	1.61	83
* Effective	HeatCon	4.47	1.30	86
	HeatEx	4.94	1.33	83
* Interesting	HeatCon	4.51	1.31	84
	HeatEx	4.57	1.25	84
Discouraging	HeatCon	3.71	1.71	85
	HeatEx	2.54	1.19	82
* Exciting	HeatCon	3.35	1.40	84
	HeatEx	3.55	1.30	82
Frustrating	HeatCon	4.61	1.81	85
	HeatEx	3.34	1.57	82
* Motivating	HeatCon	3.72	1.48	85
	HeatEx	3.93	1.36	82
Challenging	HeatCon	5.34	1.32	86
	HeatEx	4.68	1.40	82
Boring	HeatCon	3.61	1.70	84
	HeatEx	3.78	1.50	81
Usability: Virtual Instrument GUI				
The GUI enhanced the learning experience.	HeatCon	5.45	1.27	87
	HeatEx	5.43	1.24	82

Graphical presentation of the data helped me to reason about the physical processes taking place in the experiment.	HeatCon	6.00	1.10	87
	HeatEx	5.66	1.23	82
Usability: Chat Facility				
> Note: Limited to students that performed the experiment online				
The chat facility was useful.	HeatCon	5.79	1.46	38
	HeatEx	5.80	1.34	40
Team members and administrator, if needed, communicated effectively by means of the chat interface.	HeatCon	6.32	0.90	38
	HeatEx	5.95	1.16	41
Overall Experience				
The iLab heat exchanger was a beneficial learning experience.	HeatCon	4.84	1.25	86
	HeatEx	5.14	1.23	84
The iLab heat exchanger experiment was fun.	HeatCon	3.65	1.43	86
	HeatEx	4.24	1.45	84
Given the choice doing the experiment with real, remotely controlled equipment on the Web to similar experiments with computer controlled equipment in the laboratory, I prefer:				
An experiment that is remotely accessible via the Web.	HeatCon	4.49	2.01	82
	HeatEx	4.55	2.06	82
An experiment with equipment in the laboratory.	HeatCon	4.74	1.86	84
	HeatEx	4.46	1.97	83

Table 2: Selected survey scale and non-scale items for team profile, learning behavior, learning experience, usability and overall experience sections.
*** = scale item; SD = standard deviation; *n* = number of respondents included in calculations**

Students on average only expressed a slightly positive learning experience as indicated by the Learning Experience Scale means of 4.08 and 4.37. However, there was small but significant improvement from experiment HeatCon to experiment HeatEx in the view of students of the learning experience. As suggested by scale item means, students did not find the experiments motivating (3.72, 3.93) or exciting (3.35, 3.55). Additionally, students did not find experiment HeatCon enjoyable (3.68) and only found experiment HeatEx slightly enjoyable (4.17). However, student responses suggest that they did find the experiments interesting (4.51, 4.57), effective (4.47, 4.94), meaningful (4.57, 5.04), and slightly stimulating (4.28, 4.34). Non-scale items further indicate that students did not think the experiments were boring (3.61, 3.78) or discouraging (3.71, 2.54).

Looking at the HeatCon experiment, non-scale items suggest that students found it be stressful (5.39), tedious (5.21) and frustrating (4.61), but also challenging (5.34). This is supported by student comments: students indicated that the analysis portion of the HeatCon experiment was challenging but that they felt the assignment required too much work for the relatively short amount of time provided to complete to it.

> "The questions were stimulating and challenging. The length of the [assignment] was a bit of a hardship."

> "Although it was challenging and frustrating, it was a useful exercise in how to do analysis on a set of data from a real situation. Made a nice change to psets! Some more time to do the analysis as a group would have been better."

Conversely, with respect to the HeatEx experiment, students reported that they did not find it to be stressful (3.72) or frustrating (3.34) and that they found it to be only slightly tedious (4.18). However, while the experiment was challenging (4.68), it appears to have been less challenging than the HeatEx experiment (5.34). Student comments support this finding: students felt the HeatEx experiment was more straightforward and believed the length of the assignment was more commensurate with the amount of time provided to complete it.

> "The assignment was fairly straightforward both in that it was very clearly written and the concepts themselves were easily interpreted. This made the assignment much easier & more enjoyable. I understood the material much more as well, because it involved things we're actually discussed in class."

> "Much more straightforward than last time. It also made more sense."

> "The assignment was just the right length, not as long and as tedious as the last one, yet I feel like I learned the same amount."

As the Understanding Scale and Learning Objectives Scale means indicate, students reported that the experiments contributed to their understanding of experiment-specific concepts (5.13, 5.37) and met desired experiment-specific educational objectives (5.21, 5.32), respectively. Table 3 shows that all individual scale items reflect this.

The Usability survey section contains items pertaining to the usability of experiment interfaces—particularly the usability of the Virtual Instrument and chat facility that compose each experiment interface. Student responses to Usability survey items indicate that they strongly agreed that the Virtual Instrument GUI enhanced the learning experience (5.45, 5.43). They also strongly agreed that the graphical presentation of data helped them to reason about the physical processes taking place in an experiment (6.00, 5.66). Note that the higher mean rating of the latter item for the HeatCon experiment might reflect the relative simplicity of the Virtual Instrument for the HeatCon experiment (see Figure 1) compared to that for the HeatEx experiment (see Figure 2). With respect to the usability of the chat facility, students also expressed positive views. Among students that performed an experiment remotely (i.e. made use of the chat facility), the chat facility was found to be useful (5.79, 5.80). It also allowed team members and the administrator to communicate effectively (6.32, 5.95).

The survey items of the Overall Experience section support the above findings of the Learning Experience section. Students seem to have found the experiments to be beneficial learning experiences (4.84, 5.14) but not much fun: students expressed that the HeatCon experiment was not fun (3.65) and that the HeatEx experiment was only slightly fun (4.24). The Overall Experience section also asks students to rate their preference for mode of experimentation (online, in lab). Taken altogether, students viewed an experiment that is remotely accessible via the web (4.49, 4.55) and an experiment with equipment in the laboratory (4.74, 4.46) both to be favorable modes.

There is no significant difference ($\alpha = 0.05$) in the mean rating of the two modes when all students are taken together. As indicated below, however, this is not the case when Type A and Type B students are examined separately.

Selected Scale Items	Mean	SD*	*n**
Understanding (HeatCon)			
* Measuring a temperature profile.	5.34	1.08	87
* Modeling steady state and transient heat conduction.	5.31	1.09	87
* Modeling heat transfer through a composite composed of resistances in series.	5.15	1.13	87
* Choosing appropriate assumptions to make in modeling heat conduction.	4.89	1.23	87
* Applying Fourier's Law.	4.82	1.28	87
* Performing energy balances.	5.25	1.15	87
* Analyzing steady state and transient data.	5.46	1.04	87
* Developing an intuitive feel for a heat conduction system.	5.15	1.38	87
* Understanding how and why the predicted temperature profile within the disk differs substantially from the actual data for transient conduction but agrees with the data for steady state conduction.	4.92	1.38	86
Understanding (HeatEx)			
* Measuring flow rates and temperatures in a real heat exchanger.	5.02	1.09	84
* Analyzing real data and considering experimental errors.	5.46	1.22	84
* Performing energy balances on a heat exchanger.	5.20	1.23	84
* Modeling heat transfer in a plate heat exchanger.	5.28	1.27	83
* Calculating overall and individual heat transfer coefficients.	5.57	1.21	84
* Using the log mean temperature difference correction factor F.	5.50	1.24	84
* Using effectiveness-NTU relationships for performance prediction.	5.55	1.12	84
* Developing heat transfer correlations and comparing to literature.	5.37	1.22	84
Learning Objectives (HeatCon)			
* Measurement of temperatures in a real system.	5.16	1.35	83
* Analysis of real steady state and transient data and comparison with theoretical predictions.	5.31	1.13	83
* Consideration of sources of error in experimental measurements.	5.11	1.18	83
* Theory for radial conduction (steady state and transient)	5.22	1.09	83
* Energy balances in real experimental apparatus.	5.24	1.11	83
Learning Objectives (HeatEx)			
* Measuring flow rates and temperatures in a real heat exchanger.	5.18	1.14	76
* Analyzing real data and considering experimental errors.	5.38	1.15	76
* Theory for flat plate heat exchangers.	5.09	1.19	77
* Performing energy balances on a heat exchanger.	5.22	1.28	77
* Using the log mean temperature difference correction factor F and effectiveness-NTU relationships.	5.35	1.24	77
* Development of a heat transfer correlation.	5.53	1.07	77

Table 3: Survey scale items for understanding and learning objectives sections.
*** = scale item; SD = standard deviation; *n* = number of respondents included in calculations**

Table 4 and Table 5 show scale means by team type for the HeatCon experiment and HeatEx experiment, respectively. With the exception of the Team Profile Scale means for the HeatEx experiment, there is no significant difference, as indicated by independent two-tailed *t*-tests ($\alpha = 0.05$), in scale means between team types. Students of both Type A and Type B teams strongly agreed that their teams worked well together, however, for the HeatEx experiment, students of Type B teams had a Team Profile Scale mean (5.53) significantly lower than that of students of Type A teams (6.28). Comparing Team Profile Scale means between experiments, this difference appears to be due to a decrease in the Team Profile Scale mean for Type B students. Unfortunately, comments supplied by students do not suggest a reason for this decrease.

Scale (HeatCon)	Type	Mean	SD*	n*
Team profile	A	6.11	1.13	37
	B	6.02	1.00	39
Understanding	A	5.14	0.91	37
	B	5.10	0.94	39
Learning objectives	A	5.28	0.85	38
	B	5.12	0.96	36
Learning behavior while running experiment	A	4.84	1.36	38
	B	4.78	1.34	39
Learning behavior while analyzing data	A	5.36	0.92	37
	B	4.92	1.32	39
Learning experience	A	4.12	0.98	38
	B	4.01	1.33	37

Table 4: Survey scales by group type for HeatCon experiment.
*** = scale item; SD = standard deviation; *n* = number of respondents included in calculations**

Scale (HeatEx)	Type	Mean	SD*	n*
Team profile	A	6.28	0.92	38
	B	5.53	1.34	38
Understanding	A	5.47	0.88	38
	B	5.25	1.16	38
Learning objectives	A	5.37	0.87	33
	B	5.20	1.10	38
Learning behavior while running experiment	A	4.93	1.10	38
	B	4.87	1.20	37
Learning behavior while analyzing data	A	5.40	0.88	37
	B	5.19	1.35	39
Learning experience	A	4.43	0.91	38
	B	4.19	1.18	37

Table 5: Survey scales by group type for HeatEx experiment.
*** = scale item; SD = standard deviation; *n* = number of respondents included in calculations**

Experiment	Type	Mode	Mean	SD*	n*
HeatCon	A	Online	5.46	1.68	37
		In Lab	3.81	1.79	37
	B	Online	3.34	1.81	35
		In Lab	5.54	1.54	37
HeatEx	A	Online	5.21	1.78	38
		In Lab	3.86	1.78	37
	B	Online	3.82	2.09	38
		In Lab	5.03	1.95	39

Table 6: Mean ratings of experimentation mode preferences, for each experiment, by team type.
*** SD = standard deviation; *n* = number of respondents included in calculations**

Table 6 shows the mean ratings, by team type, for experimentation modes as encapsulated by the Overall Experience survey items listed at the bottom of Table 2. Students in Type A teams, who performed the initial experiment (HeatCon) online, strongly agreed with the assertion that they preferred online experimentation (5.46) and disagreed with the assertion that they preferred in lab experimentation (3.81). Students in Type A teams continued to express these feelings of preferring online experimentation (5.21) to in lab experimentation (3.86) even after performing the second experiment (HeatEx) in lab. As the values for two-tailed independent *t*-tests indicate, the differences in mean ratings of the two modes of experimentation are significant (α=0.05).

Students in Type B teams, who performed the initial experiment (HeatCon) in lab, disagreed with the assertion that they preferred online experimentation (3.34) and strongly agreed with the assertion that they preferred in lab experimentation (5.54). After switching to the mode of online experimentation for the second experiment (HeatEx), students in Type B teams still rated their preference for in lab experimentation (5.03) over their preference for online experimentation (3.82). However, as the value of a two-tailed independent *t*-test indicates, this difference is not significant (α=0.05). This is due to an increase in the mean rating given to the remote experimentation and a decrease in the mean rating given to in lab experimentation as well as increases in the standard deviation of these ratings (2.09, 1.95).

Discussion

Students overall agreed that the two experiments were positive experiences. The experiments achieved their desired educational objectives and increased student understanding of concepts related to heat conduction and heat exchange processes. In performing the experiments, students indicated that they were forced to employ higher-level thinking. They noted that they worked well with their team members. And, while students thought that the experiments were tedious and lacked excitement, they did agree that the experiments were stimulating, interesting and challenging.

There is little difference in the feelings of students on most aspects of the two experiments. However, the Understanding Scale and Learning Experience Scale means for the Flat Plate Heat Exchanger Experiment are higher than those means for the Radial Heat Conduction Experiment. Students reported that they had a slightly better learning experience, one that was less tedious, less frustrating, and more enjoyable, while conducting the Flat Plate Heat Exchanger Experiment. Comments provided by students indicate that this experiment was more straightforward and that the amount of work necessary to complete the assignment was better suited to the amount of time provide to complete it. Students also commented that they were able to gain a better understanding of concepts presented in this experiment.

The surveys seem to indicate that mode of experimentation (online, in lab) did not have much, if any, affect on learning experience. When students are broken out by team type (i.e. mode of experimentation), there are no significant differences in scale means for the Radial Heat Conduction Experiment survey. For the Flat Plate Heat Exchanger Experiment survey, the only significant difference is in the Team Profile scale means: while Type A students, who performed the experiment in lab, and Type B students, who performed the experiment remotely, both reported a very positive view of their team experience, the view of Type B students was less positive.

The experiment interfaces elicited positive responses from students. They reported that the Virtual Instruments clearly and coherently displayed information. The graphical presentation of data helped students to reason about the physical processes taking place in experiments. Overall, the Virtual Instruments enhanced the learning experience. Similarly, students found the chat facility to be useful when performing an experiment remotely via the web; it was particularly effective in allowing students to communicate with the teaching assistant.

Patterns found in the preferences of students for modes of experimentation were unexpected. While, when taken as a single group, there was no significant difference in the ratings of the two modes of experimentation by students, interesting patterns emerged when ratings were looked at among Type A and Type B students separately. The survey data seems to indicate that the initial mode to which students were exposed is a powerful influencing force. Type A students, who performed the first experiment remotely, initially rated online experimentation above in lab experimentation. Similarly, Type B students, who performed the first experiment in lab, initially rated in lab experimentation above online experimentation. After performing the second experiment, for which they switched modes of experimentation, Type A students maintained their preference for online experimentation over in lab experimentation. The Type B student mean rating for in lab experimentation was higher than the Type B student mean rating for online experimentation, but given the high variance in responses, the difference is not significant. A potential influencing factor for this is the existence of an additional component of the Radial Heat Conduction Experiment for those performing the experiment in lab (i.e. type B students). The existence of this extra component may have caused type B students to rate in lab experimentation higher and online experimentation lower than they would have if the in lab version of the Radial Heat Conduction Experiment had not included an extra component.

Conclusion

This study provides some insights into the preferences of students with respect to performing experiments in a laboratory facility versus performing experiments remotely via the web. The effect of first exposure is apparently quite strong. Students expressed a preference for whichever experimentation mode to which they were initially exposed. After being exposed to both modes of experimentation, those students who performed the initial experiment online maintained their preference of online experimentation; and those students who performed the initial experiment in lab, and who initially expressed a preference for in lab experimentation, expressed no clear preference for one mode of experimentation with significance. Given the probable biasing of the latter group of students towards in lab experimentation, caused by the additional component of the in lab version of the initial experiment, it is reasonable to expect the group might rate online experimentation more favorably if the study were repeated with an initial experiment whose in lab and online versions are identical in nature.

In spite of this oddity of student preference, students reported that both experiments produced positive learning experiences. Educational objectives were achieved by the experiments and students' understanding of relevant heat transfer concepts was improved. More importantly, the mode of experimentation does not appear to have had any notable impact on the learning experience. Given these positive findings, the web-based experiments of the iLab Heat Transfer Project should continue to be used to supplement existing courses.

References

[1] http://heatex.mit.edu/About.apsx

[2] http://heatex.mit.edu/Files/Radial%20Heat%20Conduction.doc

[3] http://heatex.mit.edu/Files/Flat%20Plate%20Heat%20Exchanger.doc

10.302 Heat Conduction Survey
October 5, 2005

We seek your help in understanding how effective the *Radial Heat Conduction* experiment was as a learning experience. Please answer the following questions by indicating your agreement with the following statements or providing answers to specific questions. Thank you.

Date______________

Your Name ___________________________________ Team Number __________________________________

Please check where you conducted the experiment: In Lab _____ Remotely _____

If you conducted the experiment remotely, indicate how your team members logged on:

Collectively assembled around one computer _____

Individually from different computers _____

It actually took my team ______minutes to conduct the experiment.

Individually, I spent ______hours to help complete the assignment.

1. Team Profile

	strongly disagree 1	2	3	4	5	6	strongly agree 7
a. My team worked well together.	1	2	3	4	5	6	7
b. Everyone on my team contributed in a meaningful way.	1	2	3	4	5	6	7
c. My team was motivated.	1	2	3	4	5	6	7
d. When collecting data, I prefer to work in a team rather than alone.	1	2	3	4	5	6	7
e. When analyzing data, I prefer to work in a team rather than alone.	1	2	3	4	5	6	7

2. Running the Experiment

Usability when carrying out the experiment	strongly disagree 1	2	3	4	5	6	strongly agree 7
a. The instructions were clear.	1	2	3	4	5	6	7
b. I had no problems operating the experiment.	1	2	3	4	5	6	7
c. I was able to make transient and steady state temperatures as required.	1	2	3	4	5	6	7
d. I was able to record and retrieve the data needed for the assignment.	1	2	3	4	5	6	7
Usability of the Graphical User Interface (GUI)							
e. All of the information was clearly and coherently displayed.	1	2	3	4	5	6	7
f. The GUI enhanced the learning experience.	1	2	3	4	5	6	7
g. Graphical presentation of the data helped me to reason about the physical processes taking place in the experiment.	1	2	3	4	5	6	7
Usability of the Collaboration Capability							
h. My team used the chat facility for communication.	1	2	3	4	5	6	7

i. The chat facility was useful. 1 2 3 4 5 6 7

j. Team members and administrator, if needed, communicated effectively by means of the chat interface. 1 2 3 4 5 6 7

Location

k. I prefer the mode (in lab or remotely) by which my team ran this experiment. 1 2 3 4 5 6 7

l. (Answer if you ran the experiment in the lab.) Using the temperature-measuring gun during the experiment increased my interest. 1 2 3 4 5 6 7

m. Controlling the heat conduction experiment by a PC did not interfere with my learning. 1 2 3 4 5 6 7

p. Please comment on the usability of the web site and the graphical user interface.
q. Please comment on the collaboration capability of the chat facility.

3. Understanding

How well did the radial heat conduction experiment affect your understanding in the following areas?

	poorly						extremely well
a. Measuring a temperature profile.	1	2	3	4	5	6	7
b. Modeling steady state and transient heat conduction.	1	2	3	4	5	6	7
c. Modeling heat transfer through a composite composed of resistances in series.	1	2	3	4	5	6	7
d. Choosing appropriate assumptions to make in modeling heat conduction.	1	2	3	4	5	6	7
e. Applying Fourier's Law.	1	2	3	4	5	6	7
f. Performing energy balances.	1	2	3	4	5	6	7
g. Analyzing steady state and transient data.	1	2	3	4	5	6	7
h. Developing an intuitive feel for a heat conduction system.	1	2	3	4	5	6	7
i. Understanding how and why the predicted temperature profile within the disk differs substantially from the actual data for transient conduction but agrees with the data for steady state conduction.	1	2	3	4	5	6	7

4. Meeting Educational Objectives

The remotely controlled experiment provided an educational experience of

	poorly						extremely well
a. Measurement of temperatures in a real system.	1	2	3	4	5	6	7

b. Analysis of real steady state and transient data and comparison with theoretical predictions.	1 2 3 4 5 6 7
c. Consideration of sources of error in experimental measurements.	1 2 3 4 5 6 7
d. Theory for radial conduction (steady state and transient)	1 2 3 4 5 6 7
e. Energy balances in real experimental apparatus.	1 2 3 4 5 6 7

5. Learning Behavior

A. Please rate how well the following phrases describe the mental operations you used while gathering data when **running the heat conduction experiment**.

	poorly						extremely well
a. Visualizing how conduction works.	1	2	3	4	5	6	7
b. Formulating a mental model of how a heat conduction system works.	1	2	3	4	5	6	7
c. Thinking about how the lab experience relates to material previously learned.	1	2	3	4	5	6	7
d. Thinking about the data as they were being collected.	1	2	3	4	5	6	7
e. Thinking about how concepts learned from the experiment could be applied to other situations.	1	2	3	4	5	6	7

B. Please rate how well the following phrases describe the mental operations you used when **completing the data analysis**.

	poorly						extremely well
a. Visualizing how conduction works.	1	2	3	4	5	6	7
b. Applying concepts discussed in readings or lecture.	1	2	3	4	5	6	7
c. Applying concepts in the theory section of the assignment.	1	2	3	4	5	6	7
d. Formulating a mental model of how a heat conduction system works.	1	2	3	4	5	6	7
e. Thinking about how the lab experience relates to material previously learned.	1	2	3	4	5	6	7
f. Thinking about how concepts learned from the experiment could be applied to other situations.	1	2	3	4	5	6	7
g.. Integrating concepts introduced at different times during the term.	1	2	3	4	5	6	7

6. Learning Experience

Please use the 7-point scale given below to indicate how well each of the following words/phrases describes the radial heat conduction learning experience. Please write the appropriate number on the line to the right of the word/phrase.

poorly						extremely well
1	2	3	4	5	6	7

a. Meaningful	____	f. Tedious	___	k. Frustrating	____
b. Uneventful	____	g. Effective	___	l. Motivating	____
c. Enjoyable	____	h. Interesting	___	m. Challenging	____
d. Stressful	____	i. Discouraging	___	n. Boring	____
e. Stimulating	____	j. Exciting	___		

7. Overall Experience

	strongly disagree						strongly agree
a. The iLab heat exchanger was a beneficial learning experience.	1	2	3	4	5	6	7
b. The iLab heat exchanger experiment was fun.	1	2	3	4	5	6	7

c. Please comment on your overall experience:

Given the choice doing the experiment with real, remotely controlled equipment on the Web to similar experiments with computer controlled equipment in the laboratory, I prefer:	strongly disagree						strongly agree
d. An experiment that is remotely accessible via the Web.	1	2	3	4	5	6	7
e. An experiment with equipment in the laboratory.	1	2	3	4	5	6	7

g. What are the reasons for your preference?

	more negative						more positive
h. If you learned that the data you obtained was generated by a numerical simulation and was not from real equipment, would it make your overall experience more positive or more negative?	1	2	3	4	5	6	7

8. Did the explanation in class of how the instructors tackled the development of the radial conduction experiment affect your perception of how engineers reason? Was this explanation useful?

9. Please provide your thoughts about your experience with

1. The computer controlled experiment

2. The assignment

10.302 Heat Exchanger Survey
November 7, 2005

We seek your help in understanding how effective the *Flat Plate Heat Exchanger* experiment was as a learning experience. Please answer the following questions by indicating your agreement with the following statements or providing answers to specific questions. Thank you.

Date_______________

Your Name ______________________________________ Team Number ____________________________________

Please check where you conducted the experiment: In Lab _____ Remotely _____

If you conducted the experiment remotely, indicate how your team members logged on:

Collectively assembled around one computer _____

Individually from different computers _____

It actually took my team ______minutes to conduct the experiment.

Individually, I spent ______hours to help complete the assignment.

1. Team Profile

	strongly disagree 1	2	3	4	5	6	strongly agree 7
a. My team worked well together.	1	2	3	4	5	6	7
b. Everyone on my team contributed in a meaningful way.	1	2	3	4	5	6	7
c. My team was motivated.	1	2	3	4	5	6	7
d. When collecting data, I prefer to work in a team rather than alone.	1	2	3	4	5	6	7
e. When analyzing data, I prefer to work in a team rather than alone.	1	2	3	4	5	6	7

2. Running the Experiment

Usability when carrying out the experiment	strongly disagree 1	2	3	4	5	6	strongly agree 7
a. The instructions were clear.	1	2	3	4	5	6	7
b. I had no problems operating the experiment.	1	2	3	4	5	6	7
c. I was able to make temperature measurements as required.	1	2	3	4	5	6	7
d. I was able to record and retrieve the data needed for the assignment.	1	2	3	4	5	6	7
Usability of the Graphical User Interface (GUI)							
e. All of the information was clearly and coherently displayed.	1	2	3	4	5	6	7
f. The GUI enhanced the learning experience.	1	2	3	4	5	6	7
g. Graphical presentation of the data helped me to reason about the physical processes taking place in the experiment.	1	2	3	4	5	6	7
Usability of the Collaboration Capability							
h. My team used the chat facility for communication.	1	2	3	4	5	6	7

i. The chat facility was useful.	1 2 3 4 5 6 7
j. Team members and administrator, if needed, communicated effectively by means of the chat interface.	1 2 3 4 5 6 7

Location

k. I prefer the mode (in lab or remotely) by which my team ran this experiment.	1 2 3 4 5 6 7
l. (Answer if you ran the experiment in the lab.) Observing the heat exchanger equipment during the experiment increased my interest.	1 2 3 4 5 6 7
m. Controlling the heat exchanger experiment by a PC did not interfere with my learning.	1 2 3 4 5 6 7

p. Please comment on the usability of the web site and the graphical user interface.
q. Please comment on the collaboration capability of the chat facility.

3. Understanding

How well did the flat plate heat exchanger experiment affect your understanding in the following areas?	poorly						extremely well
a. Measuring flow rates and temperatures in a real heat exchanger.	1	2	3	4	5	6	7
b. Analyzing real data and considering experimental errors.	1	2	3	4	5	6	7
c. Performing energy balances on a heat exchanger.	1	2	3	4	5	6	7
d. Modeling heat transfer in a plate heat exchanger.	1	2	3	4	5	6	7
e. Calculating overall and individual heat transfer coefficients.	1	2	3	4	5	6	7
f. Using the log mean temperature difference correction factor F.	1	2	3	4	5	6	7
g. Using effectiveness-NTU relationships for performance prediction.	1	2	3	4	5	6	7
h. Developing heat transfer correlations and comparing to literature.	1	2	3	4	5	6	7

4. Meeting Educational Objectives

The remotely controlled experiment provided an educational experience of	poorly						extremely well
a. Measuring flow rates and temperatures in a real heat exchanger.	1	2	3	4	5	6	7
b. Analyzing real data and considering experimental errors.	1	2	3	4	5	6	7

The remotely controlled experiment provided a vehicle for learning about	poorly						extremely well

c. Theory for flat plate heat exchangers.	1 2 3 4 5 6 7
d. Performing energy balances on a heat exchanger.	1 2 3 4 5 6 7
e. Using the log mean temperature difference correction factor F and effectiveness-NTU relationships.	1 2 3 4 5 6 7
f. Development of a heat transfer correlation.	1 2 3 4 5 6 7

5. Learning Behavior

A. Please rate how well the following phrases describe the mental operations you used while gathering data when **running the heat exchanger experiment**.	poorly						extremely well
a. Visualizing how heat exchangers work.	1	2	3	4	5	6	7
b. Formulating a mental model of how a heat exchanger works.	1	2	3	4	5	6	7
c. Thinking about how the lab experience relates to material previously learned.	1	2	3	4	5	6	7
d. Thinking about the data as they were being collected.	1	2	3	4	5	6	7
e. Thinking about how concepts learned from the experiment could be applied to other situations.	1	2	3	4	5	6	7

B. Please rate how well the following phrases describe the mental operations you used when **completing the data analysis**.	poorly						extremely well
a. Visualizing how heat exchangers work.	1	2	3	4	5	6	7
b. Applying concepts discussed in readings or lecture.	1	2	3	4	5	6	7
c. Applying concepts in the theory section of the assignment.	1	2	3	4	5	6	7
d. Formulating a mental model of how a heat exchanger works.	1	2	3	4	5	6	7
e. Thinking about how the lab experience relates to material previously learned.	1	2	3	4	5	6	7
f. Thinking about how concepts learned from the experiment could be applied to other situations.	1	2	3	4	5	6	7
g.. Integrating concepts introduced at different times during the term.	1	2	3	4	5	6	7

6. Learning Experience

Please use the 7-point scale given below to indicate how well each of the following words/phrases describes the heat exchanger learning experience. Please write the appropriate number on the line to the right of the word/phrase.

poorly						extremely well
1	2	3	4	5	6	7

a. Meaningful	___	f. Tedious	___	k. Frustrating	___
b. Uneventful	___	g. Effective	___	l. Motivating	___
c. Enjoyable	___	h. Interesting	___	m. Challenging	___
d. Stressful	___	i. Discouraging	___	n. Boring	___
e. Stimulating	___	j. Exciting	___		

7. Overall Experience

	strongly disagree						strongly agree
a. The iLab heat exchanger was a beneficial learning experience.	1	2	3	4	5	6	7
b. The iLab heat exchanger experiment was fun.	1	2	3	4	5	6	7

c. Please comment on your overall experience:

Given the choice doing the experiment with real, remotely controlled equipment on the Web to similar experiments with computer controlled equipment in the laboratory, I prefer:	strongly disagree						strongly agree
d. An experiment that is remotely accessible via the Web.	1	2	3	4	5	6	7
e. An experiment with equipment in the laboratory.	1	2	3	4	5	6	7

g. What are the reasons for your preference?

	more negative						more positive
h. If you learned that the data you obtained was generated by a numerical simulation and was not from real equipment, would it make your overall experience more positive or more negative?	1	2	3	4	5	6	7

8. Please provide your thoughts about your experience with

1. **The computer controlled experiment**

2. **The assignment**