AC 2007-1524: INDIVIDUALIZED, INTERACTIVE INSTRUCTION (3I): AN ONLINE FORMATIVE ASSESSMENT AND INSTRUCTIONAL TOOL

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production. At Ford, he also developed the first spectroscopies based on scanning tunneling microscopy. From 1986 through 1994, at the Jet Propulsion Laboratory, Dr. Kaiser developed and demonstrated the first electron tunnel sensors for acceleration and infrared detection and initiated the NASA/JPL microinstrument program.

In 1994, Professor Kaiser joined the faculty of the UCLA Electrical Engineering Department. At UCLA, he initiated the distributed networked embedded sensor field via many large collaborative programs across several departments. These combined UCLA research activities have now led to the creation of many new programs within DARPA, NSF, NASA, and in commercial technology corporations. He served as Electrical Engineering Department Chairman from 1996 through 2000. Dr. Kaiser has over 100 publications, 100 invited presentations and 21 patents. He has received the Allied Signal Faculty Research Award, the Peter Mark Award of the American Vacuum Society, the NASA Medal for Exceptional Scientific Achievement, the Arch Colwell Best Paper Award of the Society of Automotive Engineers, and two R&D 100 Awards.

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Individualized, Interactive Instruction (3i): An Online Formative Assessment and Instructional Tool

Abstract

This paper describes a novel online tool, Individualized, Interactive Instruction (3i), that enables new instructional approaches based on formative assessment. The 3i system provides real-time feedback from students to instructors in the classroom. 3i directly displays each student's progress on specific problem solving tasks that reveal understanding of instructional topics. The 3i system design ensures private and anonymous communication and thus encourages student participation. Most importantly, the combination of these characteristics allows a student-centered learning method that is convenient for students as well as for instructors. Moreover, the 3i system has been evaluated in multiple gateway Electrical Engineering and Life Science courses at the University of California, Los Angeles. This paper will describe the design and implementation of 3i as well as provide a detailed assessment of results from its evaluation.

Introduction

Traditional classroom instructions, while providing one of the more effective methods of learning, prove insufficient in many settings, especially in terms of overall student understanding of course materials. Much of the success in student learning is attributed to the interactions between the instructor and students.[1,2] It has been shown that when students are actively interacting with the instructor, they are more engaged in learning.[2] These interactions facilitate student participation, attentiveness, motivation and an overall desire to learn[3]. These are all reasons why interactivity is such a critical component in student learning.[1,4] In typical classrooms, however, interactions are often one-way and lack feedback to an instructor – an instructor provides a lecture and students are restricted to only listen. Small interactions are common but still very limited for the following reasons: 1) limited class time is available for interaction; 2) oral questioning is usually one-on-one; 3) students are often not comfortable participating in the presence of a large class; and 4) mechanisms are not available to assess student comprehension of the course materials being covered at any given point in time during a lecture.[4]

These issues are particularly important in undergraduate science and engineering courses, where learning through lectures may become monotonous, impersonal, and perceived as boring to students.[5] Recent studies report that 83% of science and engineering instructors use lectures as their primary method of teaching.[6] This leads to "open-loop" instruction, where instructors cover challenging course materials with little or no student interaction and receive no indication of student understanding.[5]

By enhancing interactions in the classroom, students will be able to better engage themselves in the classroom, and this will inevitably make learning more effective.[7] This effectiveness of classroom instructions on student learning has become a primary concern and priority in education. It is especially difficult in typical university classrooms where the student-to-faculty ratio can range from many tens to hundreds. In these environments, conventional methods that involve tracking the progress of each individual student are impractical, and often unfeasible. It is here that active learning and formative assessment techniques are particularly valuable.[5] Active learning is a student-centered approach of learning designed to better engage students in the learning materials.[5]

Formative assessment is a method to provide feedback on student learning to be used for instructional improvements.[5]

Formative assessment techniques can be quite involved and possibly require real-time analyses of students' learning processes. These techniques can be effective and there is evidence to show that they can indeed improve student learning.[8,9] More recently, technologies have been used to perform formative assessment and much literature has been published in this regard. Most of these technologies accomplish this while also enhancing student-instructor interactions.

Classroom response systems have been the most successful of these technologies.[10] A typical classroom response system is question-driven and consists of transmitters used by students to send responses to a receiver, usually developed to collect, interpret and possibly display responses of the entire class.[10] Research shows that systems of this type enhance interactivity in the classroom by providing a more dynamic and active learning environment for students and instructors alike.[4,10] One such system is the Hyper-Interactive Teaching Technology (H-ITT)[4]: a clicker-based technology that allows students to answer multiple-choice questions posed by the instructor with clickers and have their collective responses displayed. Results have shown that this system improves perceived classroom interactivity, as had been expected.[4]

Other formative assessment technology examples include audience response systems,[11,12] voting machines,[13] wireless keypad response systems,[14] and classroom communication systems.[15,16,17] All are very similar in nature to classroom response systems.

Objectives and Goals

Individualized, Interactive Instruction (3i) was developed to further advance current formative assessment technologies to better enhance the interactivity, engagement and overall student learning in the classroom. Although these technologies have been very successful in a wide variety of media, we feel that a different approach can be even more effective. 3i is a question-driven software tool that provides the instructor a real-time assessment of students' understanding of specific course materials. Furthermore, 3i provides students a feedback-based, interactive and engaging approach to learning. In more specific terms, the objectives of our system are to provide the following:

Individual Keystroke Real-Time Feedback
Our system extends the H-ITT clicker-based technology[4] by allowing the instructor to monitor students' individual keystrokes at real-time to a posed question, as opposed to only the final answer. Here, instructors are given insight into students' thought processes as they work through questions. Instructors are now able to not only rapidly observe specific mistakes, but also understand why students are making these mistakes and identify common areas of student weakness. The feedback facilitates the teaching process for instructors, especially in science and engineering courses where the problem solving process is usually more important than the final answer.[5] None of the aforementioned technologies have this capability. Furthermore, instructors can use this insight to modulate their lecture pace and topic selection according to student comprehension, an option that is not possible in traditional lectures. Instructors will be able to focus on the most challenging topics to the students at hand, a technique that improves student learning.[5] Collectively, this provides a capable formative assessment approach.

Level of Understanding

Similar to the Personal Response system[17] that allows students to indicate a confidence level (High, Medium, Low) to an answer, our system provides a level of understanding rating. This rating (presented on a 1-5 scale for a standard 3i configuration) gives the instructor extra insight on a student's comprehension of a question, in addition to the real-time problem solving feedback.

Data Acquisition
Our system provides a method to log and accumulate student data (responses, text messages, level of understanding rating) for further analyses. This is a critical component of an ongoing formative assessment process, allowing instructors to monitor the progress of students throughout an entire 3i-based course. Also, instructors are now able to provide empirical data to support previously subjective perceptions of students' understanding of class materials.

Promotion of and Comfort in Student Participation
Student participation and comfort is a critical issue when considering active instructional methods. If students are not comfortable when learning, they are unable to concentrate and fully engage themselves. Social inhibitions have been noted as one of the most common barriers for student learning.[5] In particular, students are uncomfortable raising their hands for fear that their question may lead to embarrassment in front of their classmates. These, along with other reservations, are obstacles that strongly inhibit the much needed student-instructor classroom interactions.[4,18] Our system directly addresses this issue through student anonymity. Using an anonymous medium facilitates student participation by allowing students to freely interact with the instructor and ask questions that they would otherwise be afraid to ask.

Ease of Use by Students and Instructors
Another key concern of any new technology is the ease of transition (from previously traditional means) for the consumers. Instructors and students alike are comfortable with traditional classroom instruction so it is important that our system remain compatible with this and require minimal additional resources. Although computer systems are necessary for functionality, software installment and operation are quite straightforward with very short learning curves.

System Overview

The 3i software tool consists of two applications: one supplied to the instructor and one distributed to students. 3i may be rapidly deployed in both conventional and wireless mobile computing environments. It is based on a client-server architecture, where student clients connect their applications to the instructor server application over conventional Internet Protocol (IP) networks. Once this connection has been established, the student is said to be engaged in a *3i session* with the instructor. From the instructor's perspective, a 3i session is a lecture composed of various queries (consisting of a question, answer and optional associated graphic image) that can be presented to the students. From the student's perspective, a 3i session is a series of queries (without the answers, of course) where the student is prompted to answer a question by entering a problem solution and naturally displaying their problem solving pathway. Once students are engaged in a 3i session, the instructor is able to navigate as desired through previously created queries, transmitting selected queries to the students. Thereafter, students will solve the query while the instructor monitors the progress of all students, keystroke-by-keystroke, using the instructor application that displays real-time responses for all students. This gives the instructor insight into the entire thought process of each individual student in the class, while students are able to receive instant verbal feedback based on their query responses. In addition, students are able to send text messages directly to the instructor at any time during a 3i session. This allows students to ask personal or what they may

perceive to be "dumb" questions that they prefer not to ask in the presence of the entire class. A detailed description of these components follows below.

Student Application

The student application, as shown in Figure 1, consists of three modules that are enabled only after the student is engaged in a 3i session. When a query arrives, the student can use these three modules to interact with the instructor.

Image Canvas: This displays the image that is transmitted to students as part of a query.

Question Center: The question box displays the question that is transmitted as part of a query. The answer box is editable and allows an answer to the current query to be entered. A typical answer in a Science or Engineering course may be an equation (expressed with standard keyboard characters). The process of inputting an answer is captured in real-time (keystroke-by-keystroke); that is, the answer responses appear and are displayed at the instructor system as each character arrives, providing substantial insight into the active learning process. Also, the slider bar is used by the student for indicating a level of understanding for this current query.

Message Center: This is used to send private text messages to the instructor application. Note that there is not an area to receive private messages, as most instructors prefer not to reply to individual text messages. Addressing these individual questions would be time consuming and ineffective. Rather, instructors can selectively choose some of the key points from the text messages and address them to the entire class in their spoken discussion – all while maintaining anonymity and privacy for students whose identity is not revealed.

Instructor Application

The instructor application, as shown in Figure 2, consists of four primary modules that provide student interaction and a fifth module that permits the convenient creation of a lecture.

Toolbar: This provides one button allowing creation of a new lecture, a button that permits loading of a previously created lecture, and buttons for simple navigation through the queries of a previously loaded lecture. The toolbar also displays the instructor machine's IP address – a value that is distributed to students who will connect to the instructor. The creation of a new lecture is done through a separate dialog box that allows the instructor to create a new lecture or modify an existing one. The lecture consists of a series of text question statements and optional graphics to be displayed by the students. This is convenient and enables rapid assembly of a *3i session*.

Question Center: This displays the current query, consisting of a question, an answer and an optional image.

Student Response Center: This displays the student responses, level of understanding and student IP addresses (if enabled) for the current query. It also displays the percentage of students that have some response (at least one character) typed into their answer box.

Message Center: This displays all private text messages received from students in the current *3i session.*

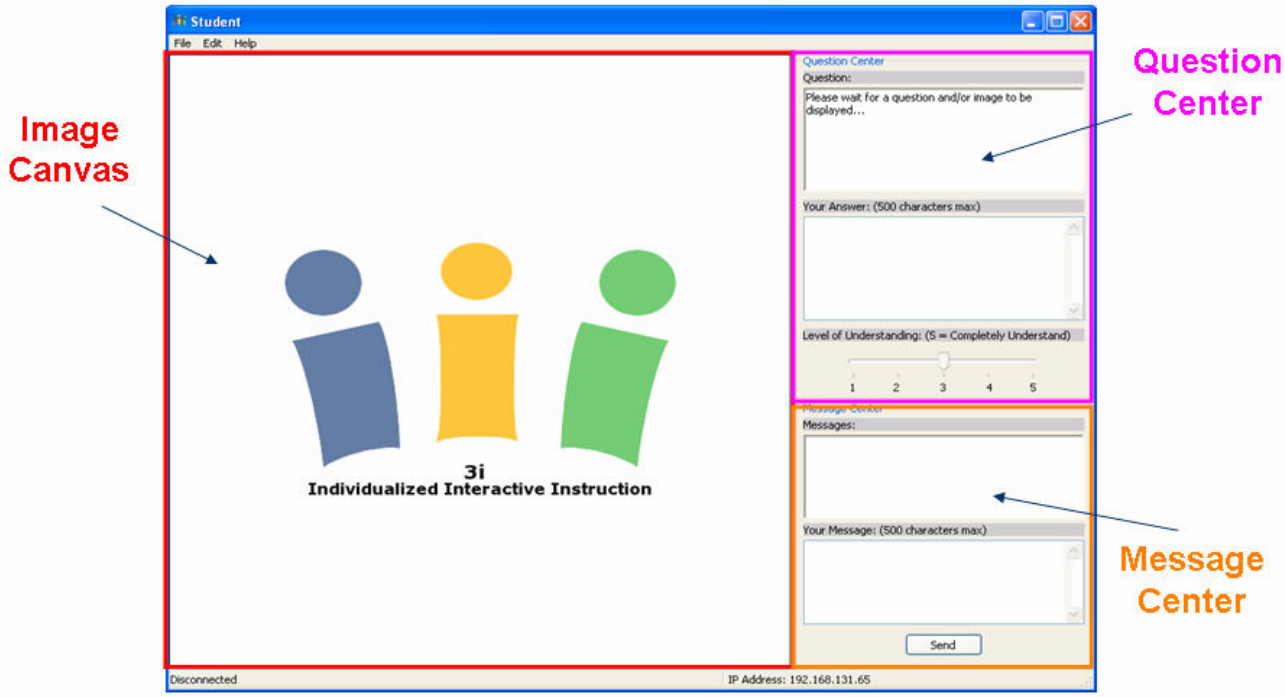

Figure 1: The student application display.

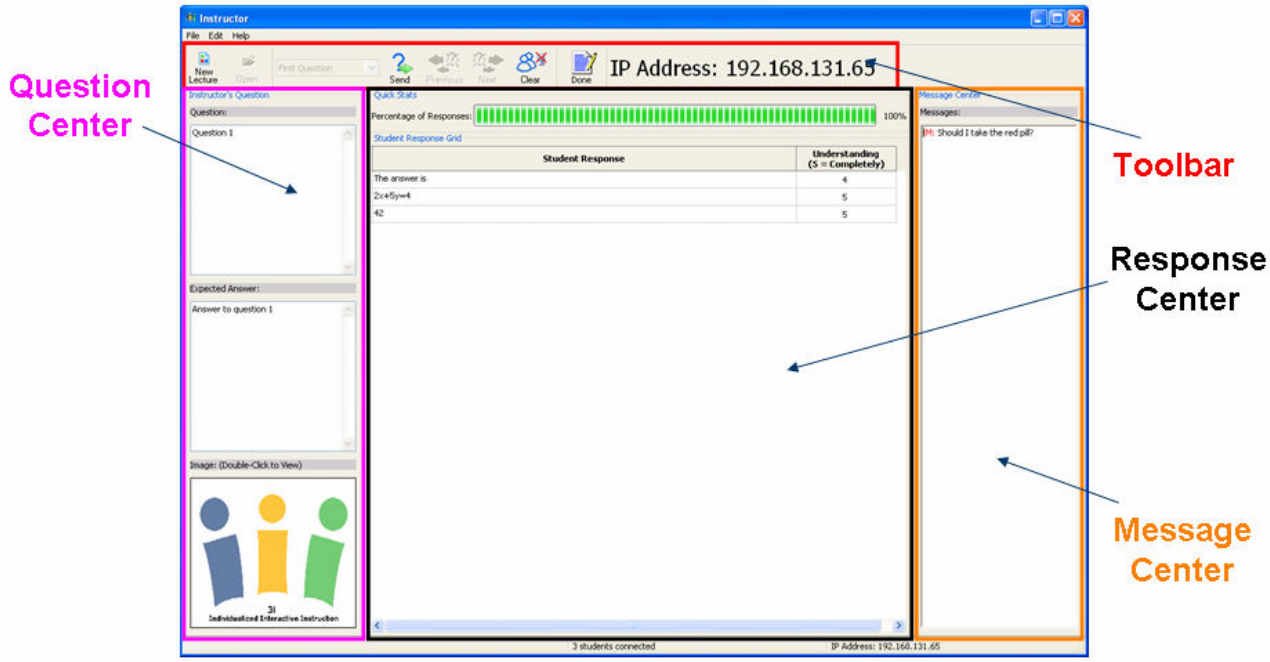

Figure 2: The instructor application display

Design and Implementation

The 3i software tool is developed in the C++ programming language using the open-source and cross-platform wxWidgets GUI (graphics user interface) library.[19] The code is modular, permitting the rapid addition and removal of functionality from the applications. This allows convenient customization based on the needs of a particular application by developers. Also, its cross-platform

nature means that students and instructors can execute 3i systems on different systems without restriction on operating system choice.

wxWidgets[19] is an event-driven architecture providing a GUI application library, where the GUI system is composed of a main event loop that calls on an event handler depending on specific user actions and other program messages. This event-driven architecture is effective and efficient for our 3i system since its operation is primarily focused on the processing of incoming socket messages, and some simple user interactions with the GUI. The user is thus able to interact with the GUI while the application performs other socket-related activities.

The networking protocol between the student applications and the instructor application presents an important scaling challenge that has been solved by this system. It is designed with speed in mind in order to permit the real-time display of many tens to hundreds clients. Figure 3 shows a visualization of the communications protocol that was developed.

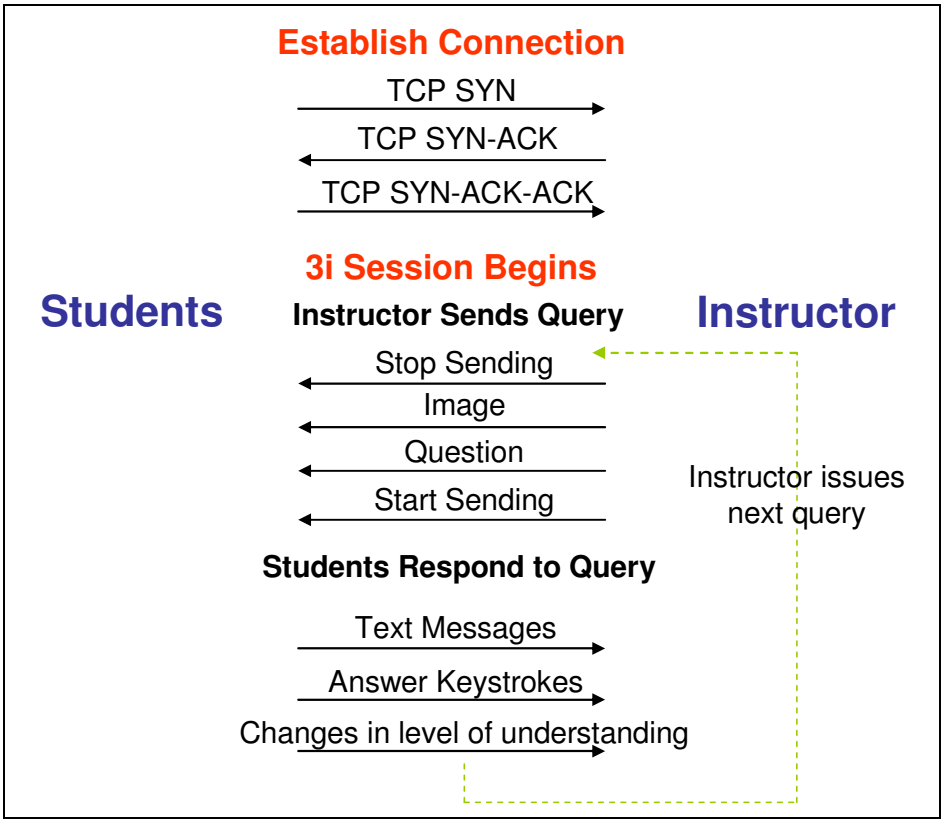

Figure 3: The Networking Protocol

Based on the wxWidgets[19] networking library, the student and instructor applications are configured to use a client-server architecture operating over TCP/IP to link applications. For 3i, a reliable and real-time protocol is required in order for the instructor to realistically visualize student keystrokes as they are being pressed. UDP is typically used when a real-time constraint is present, but it lacks the data reliability required. In this case, TCP, being a reliable service, was our best solution and provides an adequate response time for the applications at hand.

The communications protocol used involves students initiating connections to the instructor in order to establish a 3i session. After an initial TCP/IP 3-way handshake has been performed, students are

"connected" to the instructor and will participate in any ongoing or soon to commence 3i session. The instructor must initiate this step. This is done by issuing a query to all connected students. It is important at this step to ensure that all computing platform processing bandwidth and network bandwidth is preserved and devoted to image transmission in order to provide the fastest transport to the largest number of users. Prior to doing so, it must be ensured that student client applications suppress data transmission to the instructor during the query transfer (this suppression is not visible to students and is not perceived as a delay). By transmitting a "Stop sending" data packet to all students, we prevent all student applications from transmitting data during the time between the first and last student receiving the image-question combination for the current query. Once all students have received the full query, a final "Start sending" data packet is transmitted to all students, enabling them to respond to the query, send text messages, or modify their level of understanding rating. This process repeats itself for each query that the instructor decides to issue. The instructor dictates when and which queries to issue when deemed appropriate.

Once a query has been issued and students proceed solving the problem, individual answer packets are transmitted to the instructor at a minimum interval (selected to be 100ms) between packets. This rate is used to update the instructor with the most current answer typed into the student's answer box, if any modifications have been made. By using a timer to send these answer packets, the updates on the instructor machine are displayed without any perceived delay. This limited transmission rate (while not degrading responsiveness) also prevents the student applications from overloading the instructor application. In addition, packets are instantaneously transmitted to the instructor when students update their level of understanding or send private text messages. On the instructor application, all of the packets are received through a socket in an event-driven fashion. The instructor thus retains access to the GUI while packets are being received from students.

Extended testing and manual scripts have been run against our system to assess load limits and detect software bugs. Test student applications were developed with automated student keystroke generation at the maximum transmission rate. In this scenario, our system performed flawlessly with nearly 100 connected student applications. No limitations were found using the available number of test host machine resources available to perform such a test. The number of supported hosts, however, is expected to be much greater than 100, in particular when adjusting the transmission intervals to values higher than 100ms, yet still below the interval at which some delay may be perceived by the instructor (intervals greater than 500ms).

Assessment

3i has been widely used in courses at the University of California, Los Angeles in the past year. Table 1 documents the usage.

October 2005	- 3i was used during one week of discussion sections in an introductory Life Sciences course on Genetics - 6 discussion sections with ~20 students each
March 2006	- 3i was used during a final review session in an upper-division Electrical Engineering course on Electrical Circuits - 1 review session with ~40 students
April – June 2006	- 3i was used during all discussion sections in an introductory Electrical Engineering course on Electrical Circuits - 10 weeks, 3 discussion sections with ~10 students each

Aug. – Sept. 2006	- 3i was used during all discussion sections in an introductory Life Sciences course on Genetics - 6 weeks, 6 discussion sections with ~20 students each

Table 1: 3i Usage

In each occasion the system was used, students were administered surveys to analyze the effectiveness of 3i in comparison to typical discussion sections. A typical discussion section usually consists of reviewing lecture materials and discussing previous or upcoming homework assignments. The 3i-based section, on the other hand, is administered as a *3i session* where the teaching assistant presents students with a previously created lecture set of queries. These queries, of course, pertain to the topics and materials currently being covered in the course. While 3i has been used in small and large courses, our assessment discussion, below, focuses on the usage in large sessions. This is where the urgency of assessment is greatest, and both the benefits and potential challenges to 3i will be made most evident.

3i was used in alternating discussion sections of this 6-week Life Science Genetics course in the summer of 2006. Each student was required to attend two 2-hour discussion sections per week and one of these sections was administered using 3i. The discussion sections in this particular course were run by two teaching assistants. Each 3i-based discussion section was held in a computer lab, where about 20-25 students and the instructor were assigned individual desktop computers, all connected to the same local area network. Student surveys were administered after the first use of 3i (denoted as pre-test) and after using 3i for the whole six weeks (denoted as post-test).

The survey consisted of a wide variety of questions that asked students to compare 3i to typical discussion sections. Each question fell into one of five distinct categories: engagement, interaction, comfort participating, learning, and interest. All of these categories are disjoint and allow us to compare 3i and typical discussion sections in these various regards. It is important to note that these classifications are merely perceived notions and are not direct measurements, but they still convey meaningful insight to gauge the effectiveness of 3i. Each question is asked to compare a 3i-based section to a typical discussion section on a 6-point Likert scale (1: a lot less often, 2: less often, 3: a little less often, 4: a little more often, 5: more often, 6: a lot more often), and questions for all the five categories were distributed randomly throughout the survey. Furthermore, the survey contained an additional section for written comments. Please refer to the Appendix A for a list of all the questions (and their respective classifications) in the survey.

Perceived Engagement
Survey questions in this category asked students to indicate whether or not a 3i-based section helped facilitate engagement with the materials being covered when compared to typical discussion sections. Engagement in this context refers to the extent students were focused on the course materials and not distracted by other activities.

Perceived Interaction
Survey questions in this category asked students to indicate whether or not a 3i-based section help facilitate interaction with the teaching assistant when compared to typical discussion sections. Interaction in this context refers to the communications with the teaching assistant administering the discussion section.

Perceived Comfort Participating

Survey questions in this category asked students to indicate how comfortable they felt participating in a 3i-based section when compared to typical discussion sections.

Perceived Learning
Survey questions in this category asked students to judge how a 3i-based section helped facilitate learning of course materials when compared to typical discussion sections. Learning in this context refers to student comprehension and retention of course materials.

Perceived Interest
Survey questions in this category asked students to judge how a 3i-based section helped keep them interested throughout the entire session when compared to typical discussion sections.

Survey results were compiled using both the pre-test and post-test surveys. For the pre-test case, graphs were generated displaying the collective student responses from a sample size of 123 students that participated in the first 3i-based discussion section. One graph was produced for each category of questions (perceived engagement, perceived learning, perceived interest, perceived interaction, and perceived comfort participating) and average Likert scale ratings were calculated for each graph. Please refer to Figure 4 for these graphs. Also, a bar graph was produced comparing the pre-test and post-test average Likert scale ratings. Please refer to Figure 5 for this graph.

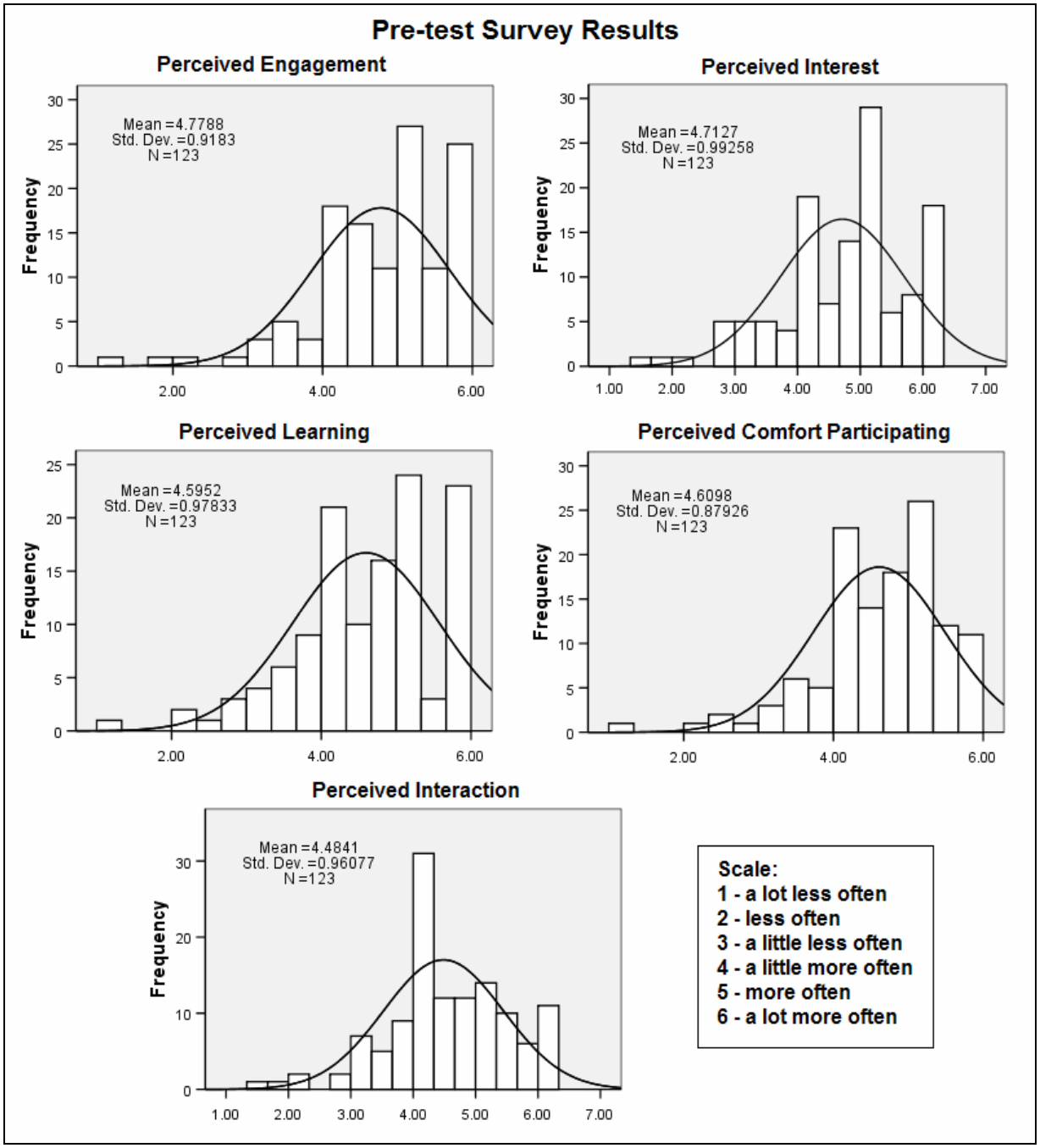

Figure 4: Pre-test survey results for 3i usage

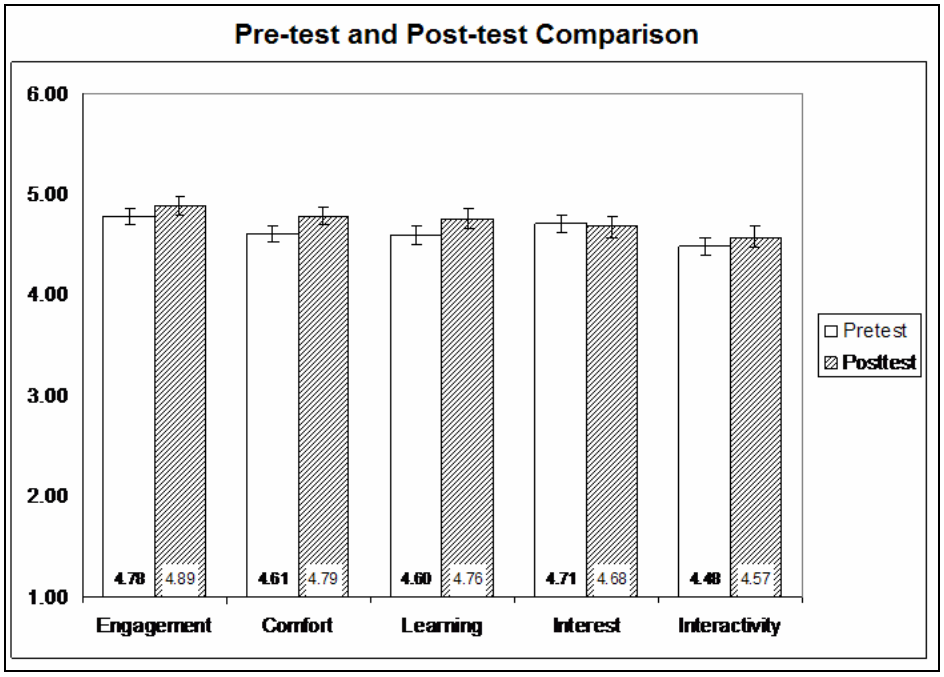

Figure 5: Pre-test and Post-test results comparison for 3i usage

In both the pre-test and post-test cases, all five categories reported favorable results for the 3i-based discussion section in comparison to a typical discussion section. The pre-test and post-test results are also consistent with one another in all five categories, when standard deviations are taken into consideration. This is extremely positive since it shows that 3i was not subject to a novelty effect: students perceived 3i the same way both after its first use after using it for six weeks. A more in-depth summary of our student results with comments (taken directly from the post-test surveys) follows.

Perceived Engagement

The results for the perceived engagement are a post-test 6-point Likert scale mean value of 4.7788. Students' perception of engagement was the highest rated process (of the five). Students felt more engaged during the 3i-based section since it encourages participation and individual problem solving, something not common in typical discussion sections. Students are usually limited to listening and watching the instructor solve problems on the board, as opposed to solving problems themselves. One student noted this difference:

"It forces me to do the problems, instead of copying down what the TA writes on the board, so I found it really helpful. I got to practice in class."

A negative finding is that some students were less engaged in the 3i-based section because of computer-related distractions. This is an inevitable drawback of the system since students tend to get easily distracted with other activities on the computer. One student noted this on the survey:

"…because it was computer-based I'm easily distracted."

Perceived Interaction

The results for the perceived interaction are a post-test 6-point Likert scale mean value of 4.4841. Improvements in perceived interactivity were also evident from student responses. Students benefited from the immediate feedback after solving problems, available in the 3i-based format. This helped uncover problem solving weaknesses that they were not previously aware of. Students noted this phenomenon:

"I liked how I was actually solving and analyzing problems on my own with immediate feedback."
"It gives the class direction and solving problems like these with a TA [instructor] right there helps because as soon as you figure out that you absolutely are clueless, the TA can explain the problem. This has helped me do a lot better in this class."

Perceived Comfort Participating
The results for the perceived comfort participating are a post-test 6-point Likert scale mean value of 4.6068.
Student comfort when participating in the 3i-based section was also highly rated, primarily because of the system's anonymity. Students are able to freely participate in the classroom interactions and social inhibitions are no longer a factor in this scenario. Students now focus solely on learning without any lingering distractions. One student noted this:
"…[I] felt no pressure in answering wrong, which made me more comfortable in attempting the problems."

Perceived Learning
The results for the perceived learning are a post-test 6-point Likert scale mean value of 4.5952.
Improvements in learning were also perceived by students in the 3i-based section. This is of particular importance since the primary goal of the system is to provide a more effective learning medium. Students felt they received exposure to practical applications of topics learned in the classroom. Also, the interactive nature of the system allowed them to receive instant feedback regarding their own problem-solving strengths and weaknesses. Various students noted this:
"The computer-based section was good because it helped me gain a better understanding of how to apply what I learned in class to real problems. After doing these problems, I felt more comfortable doing the homework sets."
"It helped a lot with learning how to solve problems and I was able to actually absorb and apply what I was learning which helped me to remember information."
"The computer-based discussion is absolutely great!! It really helps me understand my weakness in specific area."

Perceived Interest
The results for the perceived interest are a post-test 6-point Likert scale mean value of 4.7127.
Improvements in overall student interest in class discussions are a direct consequence of the increase in interactivity and engagement.

On another note, the two teaching assistants that used the 3i system throughout the 6-week course also provided very positive remarks regarding its effectiveness. While no quantitative or qualitative results were recorded, these instructors did note that 3i helped them tailor the discussion section to focus on those materials that students were struggling with, and filter out those that students were already comfortable with. In this regard, time was well spent to the satisfaction of the students. Also, both instructors felt comfortable operating the system, especially after the first two sessions, and were able to setup and run the 3i-based discussion section without assistance.

Suggestions for Usage

Like all other tools, 3i performs best under certain conditions and may be limited under others. These do not reduce the value of the tool; however, it is useful to note these circumstances in order to most effectively use 3i. The following summarizes the most important of these issues:

Instructor Familiarity
The instructor must be sufficiently familiar with the 3i tool (more specifically, the instructor application) in order to effectively administer a 3i class session. The instructor application has a short learning curve, mostly related to the creation of 3i session lectures and the mechanics of running a created lecture. This generally only requires the operation of two buttons on the console during a lecture – thus the skills are rapidly acquired.

Pacing
The instructor must also maintain an appropriate pace throughout the entire 3i session. Pacing is critical since this is one of the most frequently reported negative issues with 3i. Just as may happen in a conventional lecture, excessive time may be devoted to one topic. One student noted this as a survey comment:
"…it is very boring to answer a question and then wait 10 min. while everyone else answers it".
This is an issue that must be dealt with by instructors. Some instructors tend to overly focus on certain questions even if the majority of students already comprehend that question and are ready to move on. Instructors should use their own discretion to decide when to continue to the next question or further explain a particular question. From past experience, a pacing of around 5 minutes per question is effective for the courses evaluated here. However, this will vary according to the topic and question type.

Appropriate Question Construction
3i is most effective when questions are constructed in a certain manner. Specifically, questions should elicit a thought-provoking answer in order to truly take advantage of the individual student keystroke monitoring. Also, lengthy problems must be decomposed into questions requiring short problem solving phases. These must not be excessively involved (or too simplified) to avoid hindering the pace.

Classroom Setting
3i operates in a range of classroom settings and is most effective for class sizes of 20 to 25 students. 3i also remains effective when multiple students share a single workstation or notebook client and share the problem solving workload.

Course Supplement
3i can be used solely as an instructional tool or as a supplement to the traditional classroom instructions. Using 3i as a course supplement may be most effective and allows students to perform exam-like practice problems, while providing the instructor a better overview of the students' comprehension of materials covered in the ordinary lectures.

Please note that these conditions are simply recommendations for optimal use of the 3i system based on past experiences. Many of these issues are subjective, course material dependent and might not apply in certain applications. Learning the system and finding the appropriate pacing and question types to achieve optimal results may take practice over several sessions.

Conclusion

The 3i system has been designed and developed for formative assessment objectives and to promote active learning. 3i introduces an advance in previous classroom response technologies by providing novel means to increase interactivity, engagement and learning in the classroom. Through a simple interface monitoring student thought processes, 3i provides instructors with a substantial increase in

the depth of feedback on students' overall understanding of specific course materials by revealing student progress through problem solving pathways. The objective for enhancement of formative assessment was verified by observing the instructors' interaction and ability to accurately address student weakness in understanding. Extensive testing and usage have provided favorable results with both students and instructors expressing satisfaction with this new software tool in electrical engineering and life science courses. Future plans are for 3i to be used at an increasing number and diversity of course offerings at the author's institution. Furthermore, the 3i tool, developed as an open source application, will continue to be supported to promote the growth of a user and developer community.

Appendix A

Student Survey Questions:

Survey questions asked students to compare the 3i-based discussion section to a typical discussion section. In particular, students were asked to rate the validity of various statements on a 6-point Likert scale (1: a lot less often, 2: less often, 3: a little less often, 4: a little more often, 5: more often, 6: a lot more often). Questions were randomly distributed throughout the survey. Each question corresponds to one of five categories that are unknown to the students. Below is a summary of the questions grouped by category.

Compared to a typical discussion section, in the computer-based [with 3i] discussion section…

Perceived Comfort Participating
…I felt comfortable participating
…I felt comfortable asking "dumb" questions
…I felt comfortable if I got the wrong answer
…I felt comfortable asking questions about how to solve problems
…I felt comfortable attempting to solve problems that I (initially) did not know how to solve

Perceived Interest
…the section was interesting
…I got bored
…I paid attention to what was going on in the discussion section

Perceived Interaction
…the section was interactive
…there was a lot of discussion between the instructor and students
…I got feedback about what I was doing correctly or incorrectly
…the instructor addressed specific difficulties I had with solving problems

Perceived Engagement
…the section was engaging
…I got to practice solving problems
…I was focused on solving problems
…I solved problems instead of being shown or told the answer

Perceived Learning

…I learned to solve different types of problems
…I learned the material thoroughly
…I learned useful techniques for solving problems
…I was able to see where I went wrong with my problem solving procedures
…the discussion helped uncover what I didn't know

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