AC 2012-4426: USE OF GAMES FOR LEARNING AUTOMATED SYSTEM INTEGRATION

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Use of Games for Learning Automated System Integration

Automated systems play an essential role in the manufacturing industry. Engineers constantly design, maintain, reconfigure, and upgrade these systems to accommodate shifts in product design or manufacturing priorities. A diverse skill set is needed and often engineers require years of experience to become expert system integrators.

Often research on learning and instruction has focused on cognitive processes. However, it has been suggested that the "will to learn" is also a critical ingredient in effective instruction [1]. Malone and Lepper note that a well-designed instructional environment can motivate people to learn without using obvious external rewards or punishments [2]. One approach is to develop virtual environments in which students can learn by doing things they enjoy, such as playing games.

Squire and Jenkins observe that the video game industry has been a major influence on students' lives in recent years [3]. Mayo [4] notes that video games have the potential to directly provide massive (and massively effective) parallel education in science and engineering. Simulation-based games can help students to develop skills in real-life problem-solving, which can result in improved transfer and reduce the amount of time needed for on-the-job learning.

Simulation-based games have been very popular in training and education over the years. Forssen [5] provides an overview of how social simulation games have been used in training for different processes and purposes. Results indicate that this method enables individual learning and promotes both single-loop and double-loop types of organizational learning. Simulation-based games have been used to teach a wide range of engineering topics, including the software engineering development process [6], electromagnetics [7, 8], digital logic [9], concurrent engineering for product/process development [10], supply chain management in an automobile manufacturing environment [11], electronic/circuit card design, assembly, fabrication, and distribution [12-14], and generic manufacturing planning and quality management activities [15,16]. One interesting example is the Virtual Disk Drive Design Studio [17]. In this game, students build on three different learning styles: (1) literature search and abstract theory, (2) consultations from experts and (3) design studio. Students are asked to launch their new disk drives in a certain time frame, simulating the idea of time-to-market. Theoretcial work about line balancing program has been developed since 1980; however, over the years, as manufacturing technology advances, the complexity of the problem increases as well. Mazziotti, Armstrong, and Powell [18] designed a simulation based Line Balancing Decision Trainer with a goal of improving the skill of assembly line balancing through a series of lessons and practice sessions.

This paper will describe the development of a game to help students to learn about industrial wiring of an automated system. Industrial wiring is an essential part of system integration—in combination with ladder logic programming, which synchronizes the motions of the I/O devices—making it possible for automated systems to mass produce products. Figure 1 is a flowchart showing the structure of the game. The game consists of three parts: quiz, wiring exercise, and assembly line design. The rationale behind the quiz, which is patterned after "Who Wants to Be a Millionaire," is to help students review concepts related to interfacing devices, such as functions and components for various types of sensors and relays. After the quiz, students move on to a wiring game, which allows them to practice wiring basic industrial components (switches, push buttons and relays), sensory devices (proximate sensor, optical sensor), and power supplies to input/output modules of a Programmable Logic Controller (PLC) that controls an automate assembly line. The learners also receive step by step support as they complete the entire circuitry. Finally, an automated system design game allows students to design a layout for a cell phone assembly line. The games allow students to perform realistic tasks in a virtual environment that allows them to opportunities to make mistakes safely and practice until they are proficient in a skill. Results from an evaluation with 32 undergraduate students are presented.

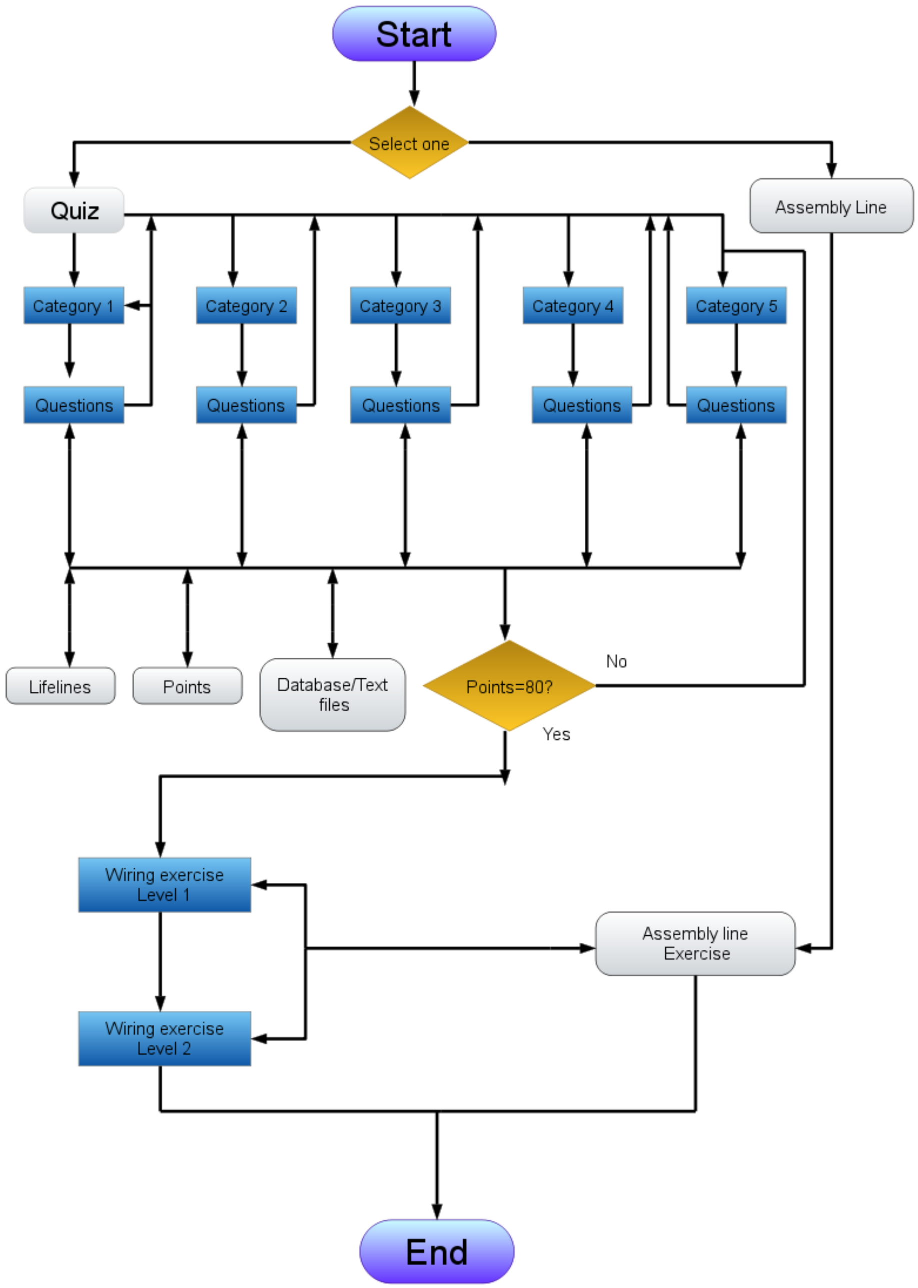


Figure 1. Industrial Wiring Game structure.

At the start of the game, the user is presented with two options—either-to go to the quiz level or the assembly line level (Figure 2). Wiring exercises serve as a second level in both scenarios. When the player clicks on the quiz option, he is presented with a screen for the quiz level (Figure 3). The quiz presents questions in five categories, such as relays, proximity sensors and optical sensors. After clicking on a category, the user is presented with questions associated with that particular category. Different categories have different numbers of questions. Instructions are on the left, question numbers are listed in the middle, and available lifelines are on the right (Figure 4). Figure 5 shows an example of a question. The lifelines are phone a friend, 50-50, and audience poll.

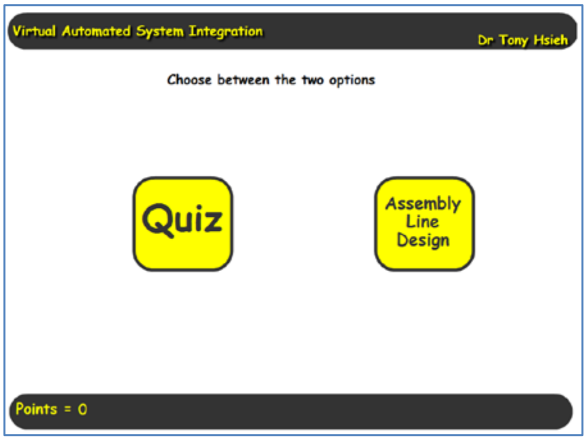


Figure 2. Start page for game.

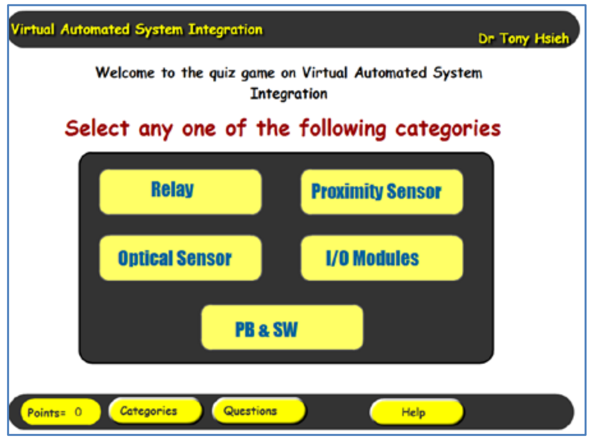


Figure 3. Quiz topic categories.

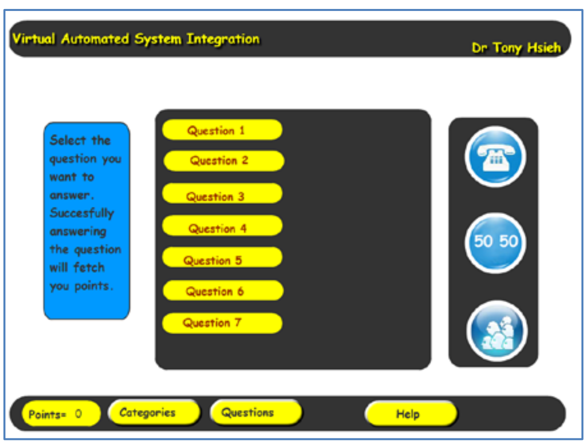


Figure 4. Question list.

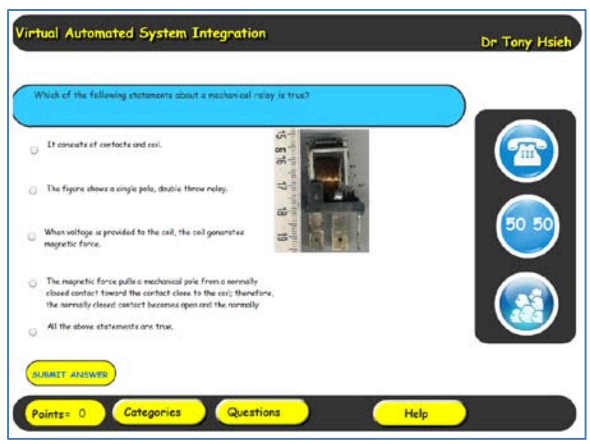


Figure 5. Sample quiz question.

Phone a friend

This lifeline allows the player to call a virtual friend (Figure 6). The virtual friend who is a software agent will tell the player what he thinks of as the correct answer (Figure 7). The probability that the virtual agent will give the correct answer is only thirty percent. The player can either make a decision using his better judgment or go for another lifeline.

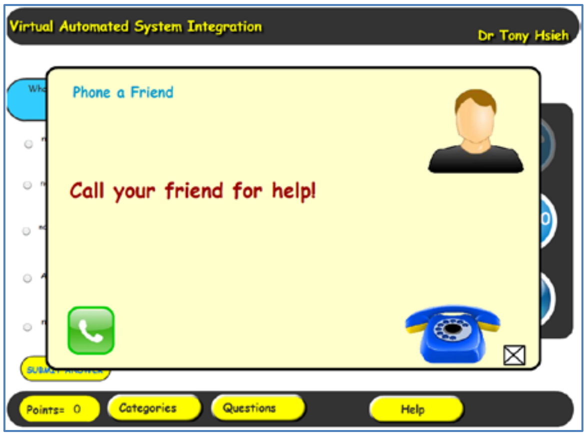


Figure 6. Phone a friend prompt.

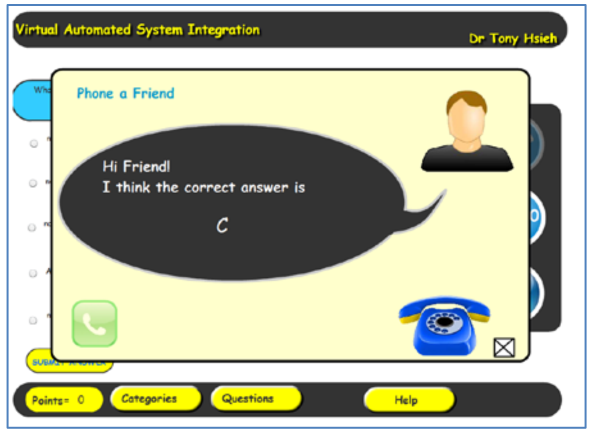


Figure 7. Phone a friend response.

50-50 (Fifty-Fifty)

When the 50-50 button is clicked, two wrong answers are hidden, improving the chances of the user selecting a correct answer. After using this lifeline, the player has a sixty percent probability of getting a right answer.

Audience poll

Clicking the audience poll lifeline opens a window with a bar graph showing the percentage of a virtual audience who thinks a particular answer is correct. For example, in Figure 9, the bar graph indicates that 80% of the virtual audience thinks that answer “B” is correct. This lifeline has eighty percent chance of yielding a correct answer for the player.

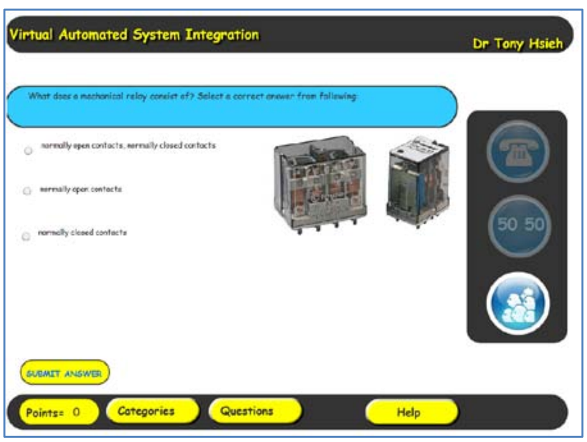


Figure 8. Audience poll button.

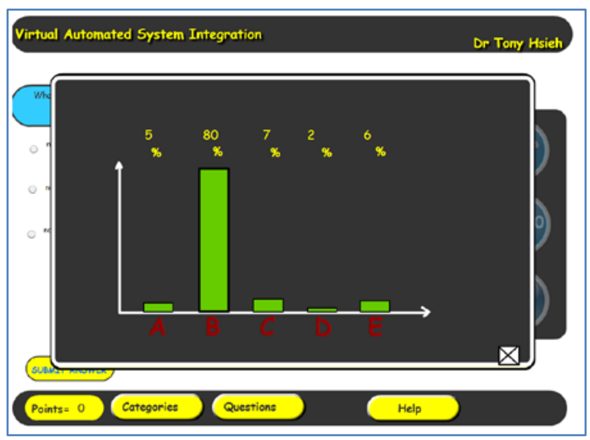


Figure 9. Audience poll screen.

Each of the lifelines can be used only once per category. After using a lifeline once, the button is automatically disabled. The button is activated again only when the user selects a new category and if he has not used his lifeline in that other category of questions.

Points

Each successful answer earns points for the user. Answers to some questions give only one point to the user while, others fetch as high as five points. The goal is to gather enough points to advance to the next level. The minimum number of points required to reach the next level is 80.

After collecting the required 80 points, the user is presented with an option to advance to the next level. Player can choose to advance right away or answer more questions and advance later.

Wiring levels

The wiring levels are simple to complex PLC wiring exercises where students are supposed to interface multiple devices with each other. Wiring exercises are grouped in three levels. Figure 10 shows the first exercise in level 1. It is meant to test students' knowledge about connecting a switch to an input power source.

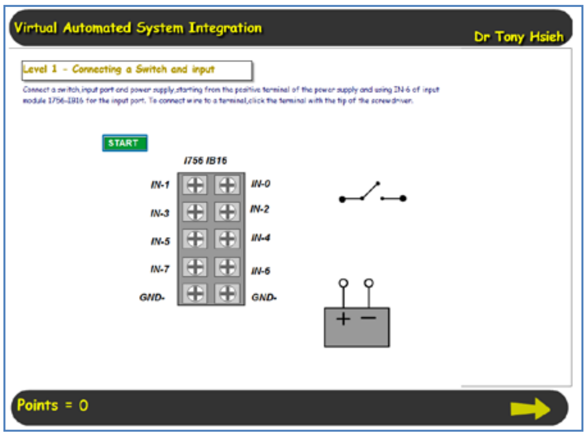


Figure 10. Sample level 1 exercise

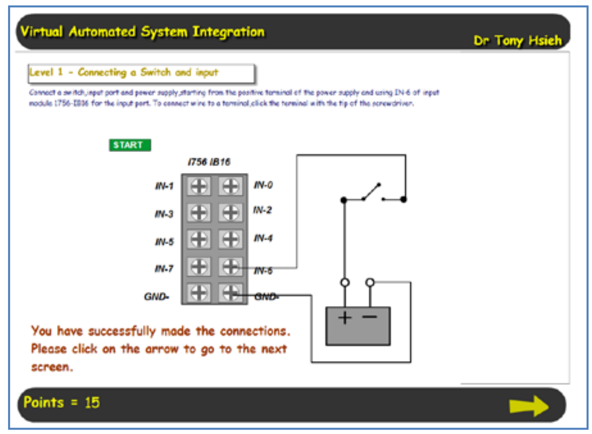


Figure 11. Completed level 1 exercise.

The student is given all the necessary details for finishing the exercise. After hitting the start button, a wire starting from a terminal appears on the screen. The wire's open end moves with student's mouse. The student is supposed to click on the appropriate terminal to make a connection between the two terminals. If the student clicks on the wrong terminal where connection cannot be made, a warning sound is generated and a "Stop" sign appears on the screen over or near the wrong terminal. The stop sign disappears after 3 seconds. If the student makes a right connection, the wires starting point shifts to a new terminal. Now the student has to click on another terminal that is appropriate for the new starting point. This goes on until the student has finished all the connections, at the end of which a message appears on the screen telling the student that they have finished the exercise and can move onto the next one by clicking the arrow at the bottom right. After successful completion of level one-exercise one, the user earns fifteen points. The number of points earned after completing each exercise varies. Figure 11 shows a completed wiring interface for the first exercise.

After completing each exercise, the student is presented with a new exercise. Figures 12-15 show sample exercises for levels 2 and 3. After completing the last exercise in level three, the user is shown a congratulatory message (Figure 16).

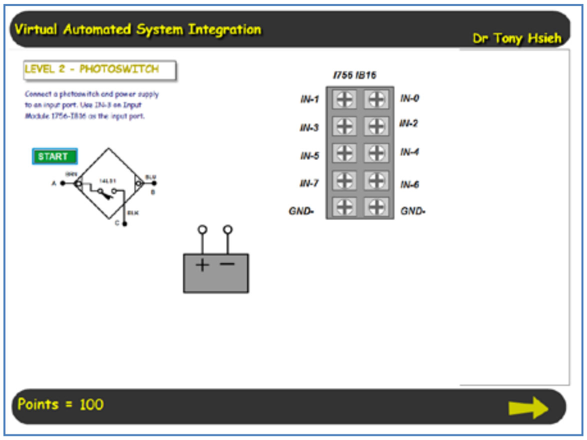


Figure 12. Sample level 2 exercise.

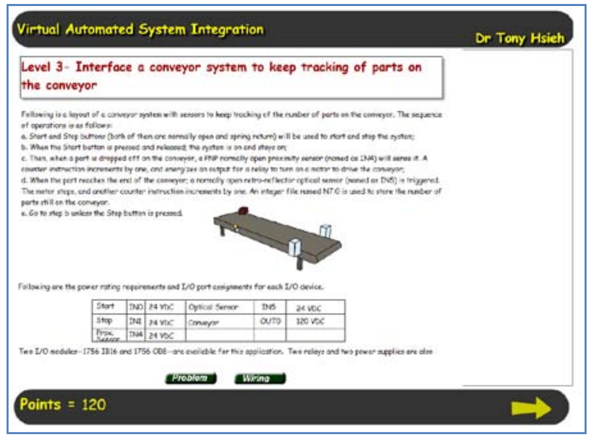


Figure 13. Problem description for sample level 3 exercise.

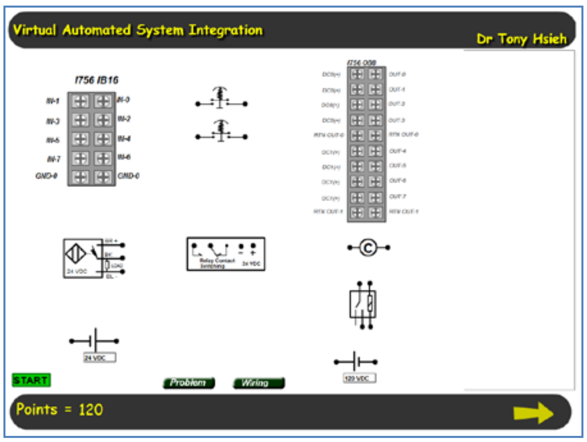


Figure 14. Components to be wired for sample level 3 exercise.

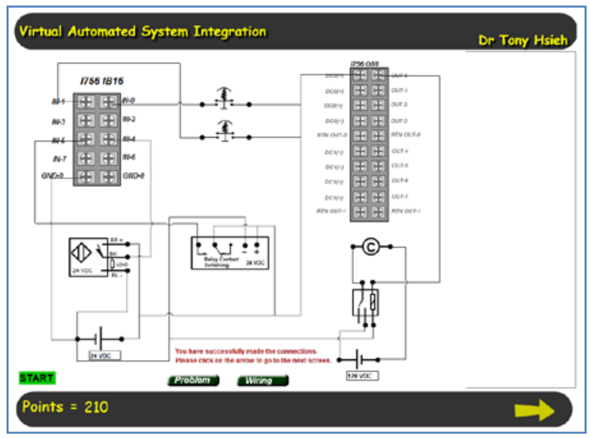


Figure 15. Completed level 3 exercise.

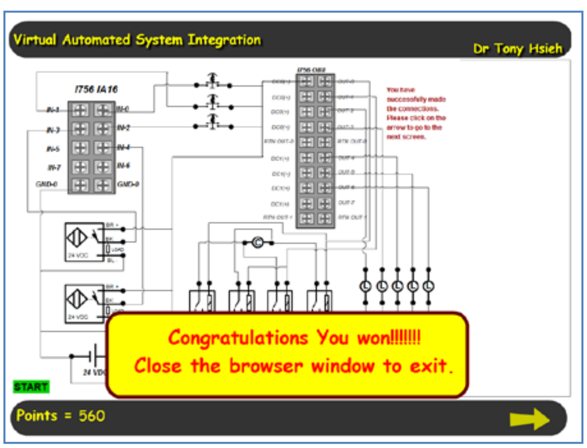


Figure 16. Congratulatory screen at end of wiring exercises.

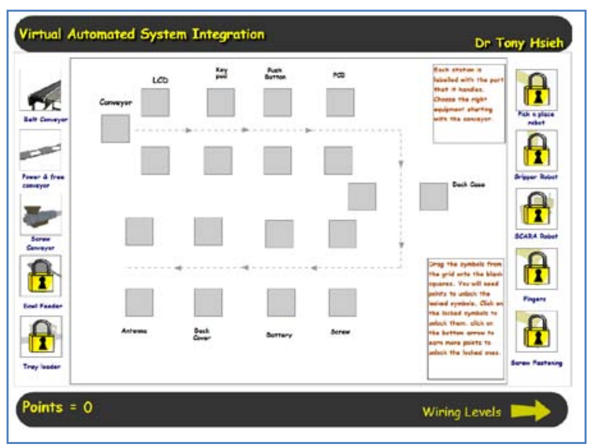


Figure 17. Assembly line level.

Assembly line level

Figure 17 shows the main page for the assembly line design level. User's task is to fill the empty boxes in the center of the screen with appropriate equipment to design an assembly line that will manufacture mobile phones. Some of the equipment symbols are locked. User can unlock the locked equipment by playing the wiring levels. The wiring levels are the same as in the quiz scenario. After successful completion of each level, the player gets points that can be used to unlock the equipment. The player can then drag and drop the equipment symbols onto the right boxes to finish the layout.

Figure 18 shows the architecture for the game.

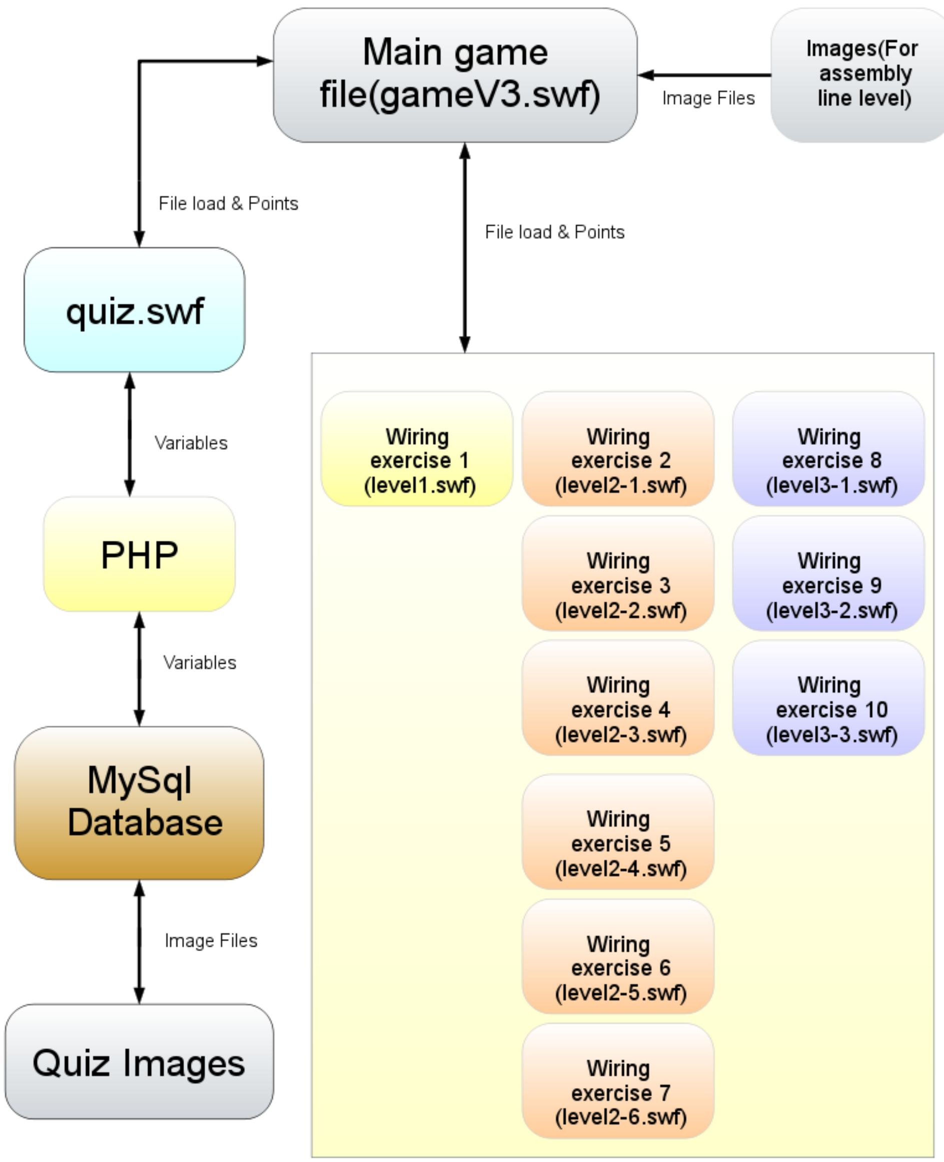


Figure 18. Architecture for industrial wiring game.

Game Evaluation

The game was evaluated by 32 undergraduate students. The goals were to determine:

- Did the game help students to learn more about basic I/O (input and output) components, sensory devices (optical and proximity sensors) work, and how to interface them to the I/O moduls of PLC?

- Student opinions about various aspects of the game, such as user friendness, features, objective, emphasis on important information, use of multimedia, and relevance to their education

- Student comments

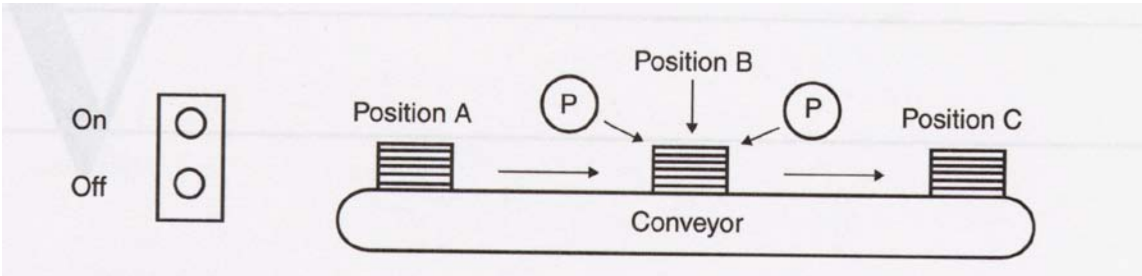
Participants, Materials, and Experimental Procedures

Participants. Participants in this evaluation were 32 undergraduate students who are currently taking Manufacturing Automation and Robotics course where they were studying how to interface I/O devices to a programmable logic controller on an automated assembly line. Evaluation activities took place during recitation time.

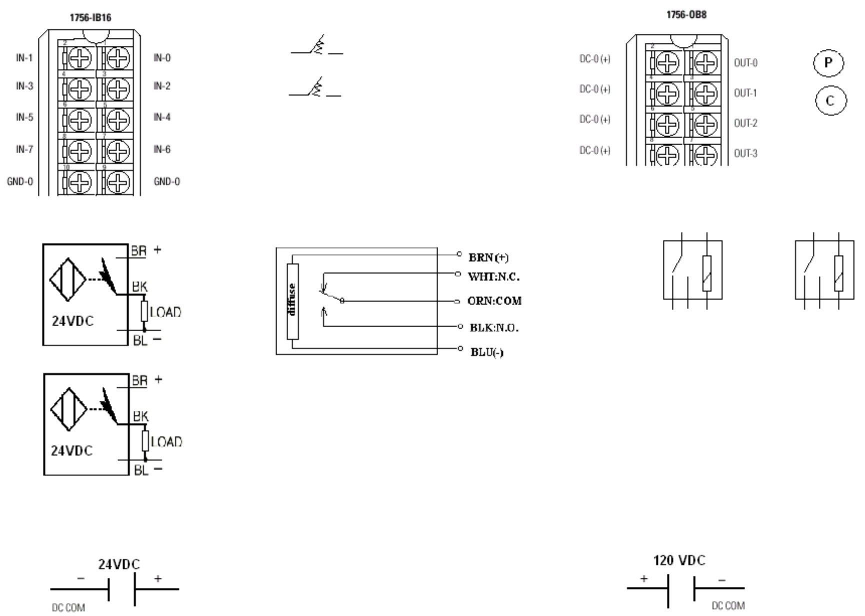
Materials. Students' knowledge of automated system design was assessed using a test consisting of a large scale industrial wiring problem for which they had to interface switches, push buttons, relays, sensors and I/O modules of a PLC controlling an automated assembly line. Below is a sample problem:

PRE_TEST - Programming and Interface I/O Devices to PLC I/O Modules:

When an *On* button is pushed, a stacker (S) starts stacking plywood sheets at station A. Stack height is controlled by a PLC counter instruction, not a height sensor. A photoelectric sensor is mounted by Position A. Every time a piece of plywood is placed on top of the conveyor, the photoelectric sensor (normally open) will be triggered. When 15 parts are stacked, the conveyor (CV) comes on and moves the stack to position B. A proximity sensor (PNP normally open) is used to stop the conveyor at B. At B, paint (P) is applied for 12.5 seconds. After painting is complete, the conveyor automatically restarts. The conveyor then moves parts to position C. Another proximity sensor is used to stop the conveyor at C, where the stack stops automatically and the stack is removed manually. The stop button stops the process anytime it is depressed. Assume that only one stack is on the conveyor at a time. *On* and *Off* buttons are normally open and spring return. In addition, all the sensors are normally open. Following are the system layout, power rating requirements and I/O port assignments for each I/O device. Two I/O modules—1756 IB16 and 1756 OB8—are available for this application. Two relays and two power supplies are also available. Please write ladder logic and make the necessary wiring of I/O devices to I/O modules, relays and power supply for this application. The layouts of the I/O modules, I/O device, relays and power supplies are also displayed below:



Start	IN1	24 VDC	Stop	IN0	24 VDC
Prox. Sensor #1 – Position B	IN2	24 VDC	Painting Process	OUT0	120 VDC
Prox. Sensor #2 – Position C	IN6	24 VDC	Conveyor	OUT1	120 VDC
Optical Sensor #1 – Position A	IN4	24 VDC			



After playing the game, students also completed an opinion survey. This survey asked students to rate various characteristics of the prototype on a 7 point Likert scale. Students rated prototype features, objectives, use of multimedia, instructional sequence, interaction with computer, emphasis on important information, relevance to education, and overall quality.

<u>Procedure</u>. Because the instructional effectiveness of the game was unknown and because we did not want the evaluation activities to interfere with students' learning, the unit on automated system design was taught in the usual way with lectures followed by lab. The evaluation activities were treated as additional lab activities. We evaluated students' knowledge before and after using the game. Figure 19 shows the sequence of the evaluation activities.

Figure 19. Evaluation event sequence.

Data Analysis and Results

This section summarizes results in terms of instructional effectiveness (as measured by the tests), student attitude (as measured by the opinion survey), and student comments.

Test Data. We analyzed the test data to see if there was statistically significant score improvement among tests. Two stages of tests were performed on the data sets. In stage I, Shapiro-Wilk's test is used to test the normality of the data set. If the data set follows a normal distribution, then a t-test can be used to do the paired data comparison. However, if the data set fails the normality test, a Wilcoxon Ranks test will be used to perform paired data comparison. The null hypothesis H_o for stage I is that there is no difference between the distribution of the data set and a normal distribution. The null hypothesis H_o for stage II is that there is no difference between the two sample sets. Two different tests were conducted; ***Test 1*** (after lecture, but before prototype), and ***Test 2*** (after prototype) for the entire class Fall 2011.

The analysis results revealed that the null hypothesis was rejected for average test score and standard deviation of test score. This suggests that using the game causes significant improvement in learning. Table 1 summarizes the test statistics, critical value and conclusions for each test, where the null hypothesis is $\mu_d = 0$, sample size for industrial wiring is 32, and the α value is 0.05. The average score before and after the game is 71.2 versus 91.3. The variance in test scores before and after the game is 26.2 versus 8.7.

T1 VS T2

Shapiro-Wilk Normality Test:

Shapiro-Wilk's W = 0.9623

Probability = 0.4577

P>0.01 Do not reject Null Hypothesis

Table I: t test of mean and f test of variance for industrial wiring game

	Test statistic	Critical value	Conclusion
After Lecture vs. After Game (t-Test)	4.3375	2.0395	Reject Null Hypothesis
After Lecture vs. After Game (F-Test)	9.0508	1.8221	Reject Null Hypothesis

Opinion Survey. We also computed means for the two groups on the opinion survey. Figure 20 summarizes these results. Student ratings were positive for all items. In general, students felt that the prototype was interactive, relevant, and easy to use and understand.

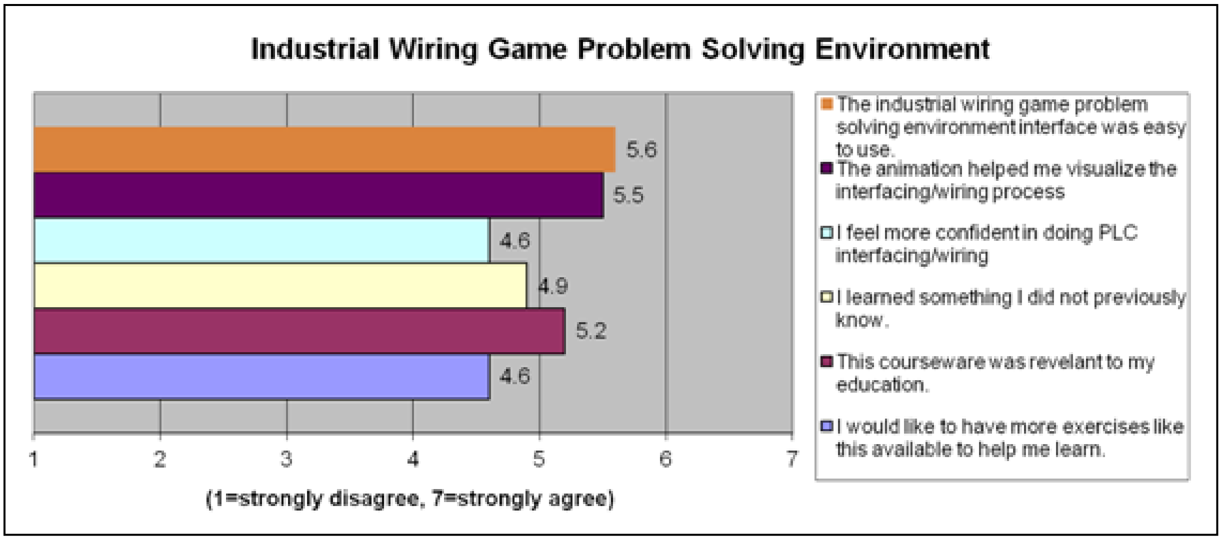


Figure 20. Summary of student opinion survey data.

Student Comments. Student comments can be summarized as follows: 1) Many students liked the game. They felt being able to visualize the wiring and interfacing worked was very helpful. 2) Some students suggested that adding explanations about why the wiring should be a certain way would be helpful. 3) Overall, students thought the game was helpful and supplemented the lecture well.

Student Learning Style Survey. Felder and Soloman's Index of Learning Styles (ILS) was administered to assess students' learning styles [19]. The ILS is a 44-question survey that asks users about their learning preferences. The Index ranks users along four attribute continuums: Active/Reflective, Sensing/Intuitive, Visual/Verbal, and Sequential/Global. Each attribute pair (e.g., Active/Reflective) represents opposite ends of a 12-point scale. More information about the ILS can be found at http://www.ncsu.edu/felder-public/ILSpage.html

Figure 21 shows the summary of the student survey. A tendency is that this group of student tends to be more Active, Sensing, and Visual. The Visual part is also consistent with results from the opinion survey; that is, on a 5.5 out of 7 point scale, students agreed that the wiring exercise helped them to learn. Figure 22 shows that all the data points are distributed on the Active side with more concentration on 9A and11A.

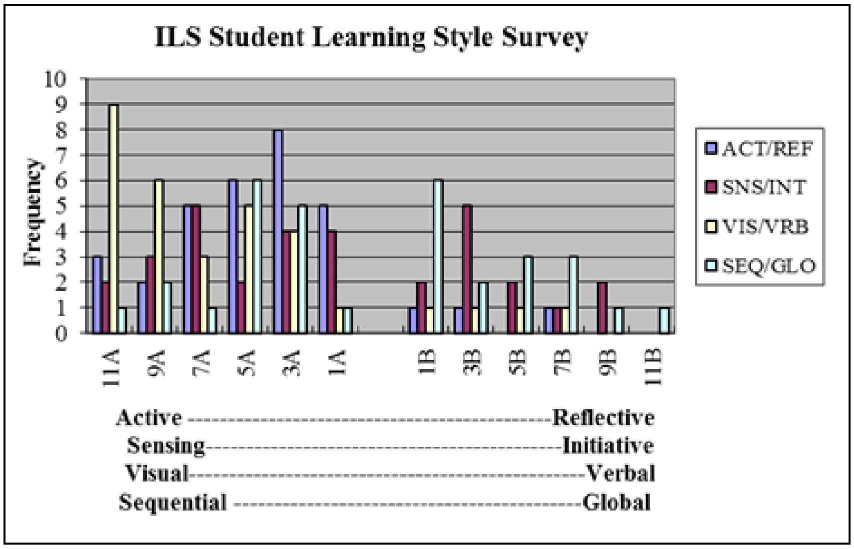


Figure 21. Summary of ILS results for four attributes

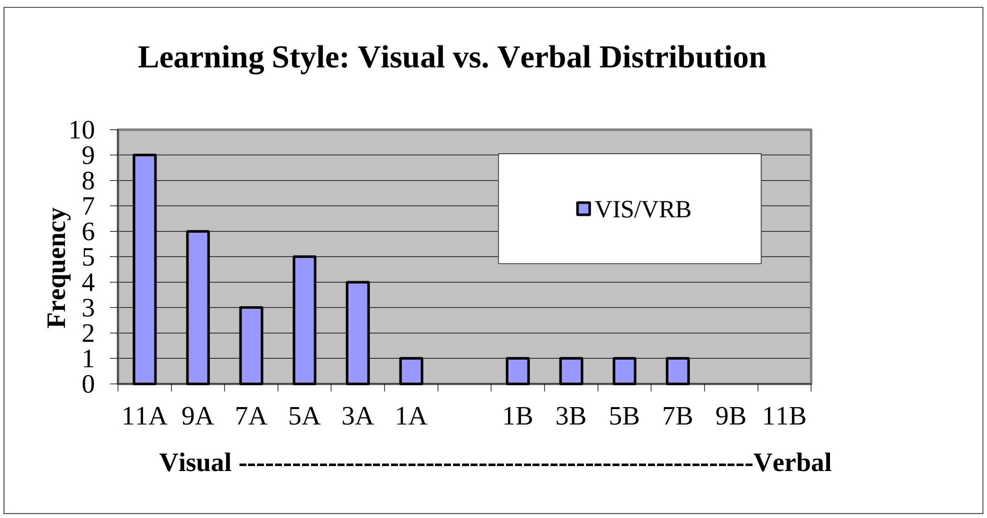


Figure 22. Summary of ILS results for Visual vs Verbal attribute.

Conclusion and Future Directions

Based on these results, we may conclude that the design of the Industrial Wiring Game is instructionally effective, and that students' subjective impressions of the system remain positive. It appears that we may safely continue to develop and enhance similar types of games. Second, the most popular instructional activity continues to be the educational animation and game, probably because they *help students to visualize* relationships between switch/button manipulations, interface with sensors to the I/O modules of PLC that controls an automated assembly line. Thus continued use of such animation and game to illustrate command functions and other complex concepts would appear to be a good instructional strategy.

We have briefly described continuing steps in the process of developing a game environment for learning industrial wiring for automated system integration. So far, our evaluation results have been very encouraging. We are currently in the process of developing more games. Future games will allow students to design automated systems and robotic work cells. Also, other equipment such as power and free indexing conveyor, Human Machine Interface, Motor Motion Drive unit, and Machine vision will be included as part of an automated system. Ultimately we hope to have a complete system that can be used not only by undergraduate students, but also by high school students and industry professionals. Future directions include investigating (1) how to teach complex topics (such as complicated wiring) with overloading working memory; and (2) how to design games that can accommodate individual differences in working memory.

The industrial wiring game provides a fun and interactive way to learn concepts related to PLC wiring. More wiring levels can be added later on to make the game more challenging. The game is designed such that the questions in the quiz can be easily replaced. Existing questions could be replaced with new questions to further modify the game.

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