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ABSTRACT

This usability study measured the ability of educators to master advanced computer programming concepts through the OWI Robotic Arm Trainer and PC Interface. Research findings revealed that the lack of prior computer programming experience did not impact the ability of each participant to successfully program his/her robotic arm. However, the absence of a detailed instructional manual detracted from the product's usability. Future directions for research and the suitability of the robotic arm for use in an online teacher preparation course in robotics technologies are discussed at the conclusion of this paper.

Keywords: Robotics, Teacher Preparation, and Human-Computer Interaction.

INTRODUCTION

According to the United States Department of Education [10], traditional academic programs do not offer training that will adequately prepare K-8 public school students to meet the demands of the contemporary workplace. Academic programs that are based on a framework of industry-based skill standards can present a consistent educational training experience that will result in skill transferability and increased worker mobility [11]. Skill standards define the technical knowledge, abilities, and dispositions that workers must obtain in order to succeed in certain occupations [6]. Through their participation in professional development training activities, educators must develop methods for integrating workplace skills such as problem-solving, collaboration, and the development of information and communication technology (ICT) skills into established academic content areas [2].

ROBOTIC TECHNOLOGIES AND SKILL STANDARDS

Over the past several years, robotic technologies have slowly made their way into the K-8 curriculum as a means of facilitating problem-solving, collaboration, and the development of information and ICT skills [1]. In order for their skills to be marketable, students must become proficient in the use of technology and demonstrate a sound understanding of the nature and operation of technological systems [11].

Robotics technologies hold a promising future for educational applications since these resources provide educators with opportunities for connecting curricular content to workplace skills and competencies. The most widely used model of the skills demanded by employers was developed by the United States Department of Labor, Secretary's Commission on Achieving Necessary Skills (SCANS) [9]. The SCANS model divides the development of industry-based skills into categories that are derived from foundation skills and workplace competencies. Foundation skills are comprised of basic skills, thinking skills, and personal qualities. Workplace competencies include the ability to interact with people, manage resources, evaluate information, understand systems, and apply technology.

CONTEXT AND GOAL OF THE STUDY

Through their participation in the course titled *Special Topics in Computer Education*, educators are introduced to the trends, developments, and current issues in the field of educational technology. This graduate level course is offered at Sacred Heart University in Fairfield, Connecticut [8]. Curricular topics are selected on the basis of student interest and the availability of emerging technologies. Methods for the development of instructional materials that combine content knowledge, ICT skills, and industry-based skill standards are an integral part of the curriculum.

The role of robotics and automation in K-12 education is currently under investigation. Content delivery is facilitated through blended-learning which is a combination of on-campus and online sessions. However, it is the intent of this researcher to convert the course to a distance learning format. In order to determine course competencies, a usability study was conducted that measured the ability of educators to independently master advanced computer programming concepts through the OWI Robotic Arm Trainer and PC Interface Kit [7]. Research findings revealed gaps in student comprehension that led to the development of supplementary instructional support materials.

METHOD

Design

Usability metrics include measurements that are relative to a user's performance on a given series of tasks [4]. In this study, measurements reflected effectiveness, efficiency, and user satisfaction. The mean task completion rates, mean goal achievement rates, mean time on task, mean completion rate efficiency, and mean goal achievement efficiency were calculated for the following three tasks:

- Setup / Uninstall Hardware and Software;
- Manipulate the Robotic Arm PC Interface Software; and
- Program the Robotic Arm to Run Autonomously.

Participants

According to Nielsen [4; 5], the use of three to five participants will adequately portray diversity in user behavior and shed insight into what is unique and what can be generalized in a usability study. Participants in this study were recruited from a group of graduate level education students having no prior computer programming experience. The group included two females and one male, ranging in ages from 30-49. All three participants indicated that they were capable of operating small hand and power tools. Each participant had prior experience in the use of a technical manual for assembling a variety of items including; computers, bicycles, outdoor grills, furniture, and models. The amount of time participants had previously spent in operating a computer for personal use ranged from 10 hours to more than 20 hours per week. Two participants were eager to try new technologies and experiment on their own. One participant responded that although he/she was an independent learner, tutorial assistance from the instructor was required during the introduction of new technological concepts and skills.

Materials

Each participant received an OWI Robotic Arm Trainer and Robotic Arm PC Interface Kit [7]. The OWI Robotic Arm Trainer is an educational robotics product that is composed of a translucent plastic material. Parts require no soldering and the kit can be assembled in a few hours through the use of small hand tools. The arm is powered by four D cell batteries and functions in the same manner as an industrial robotic arm that is used for pick-and-place and/or product assembly. Users manipulate a five-switch control box to manually control each of the robotic arm's five direct current motors. A small light is wired to each motor that draws attention to the one that is moving. Motors are protected with clutch mechanisms that prevent damage, even when an attempt is made to extend a joint beyond its limits. This feature makes the arm safe for children in primary grades to operate.

In addition to manual controls, users also have the ability to program and operate the arm by using a supplemental interface kit to attach it to a personal computer. The interface kit used in this study consisted of an external interface card, parallel printer cable, and Windows®-based software. The interface card and printer cable connected the robotic arm to the computer's parallel printer port.

Software is included in the interface kit that enables real-time control of the robotic arm through an icon-based, interactive scriptwriter. A variety of actions such as gripper open or close, elbow up or down, wrist rotation, and/or base rotation can be selected. Software menus are labeled in familiar terms including; File, Edit, View, and Help. The File menu enables users to create a new program, open a program, save a program, and/or print programming script. Scripts containing up to 99 individual robotic arm movements can be programmed by the user. The script can then be saved and reloaded from the computer's hard drive. Script files can be programmed to automatically replay and are useful for demonstrating computer controlled automation and/or animatronics.

In addition to hardware and software, this usability study included several data collection instruments. The following instruments were developed by this researcher and incorporated into the study:

- Test Overview and Informed Consent Form;
- Pre-Test Questionnaire;
- PC Interface Usability Evaluation Workbook;
- PC Interface Usability Task Sheet; and
- Post-Test Questionnaires.

Procedure

Prior to the start of the study, participants were provided with an overview of the study's usability tasks and were asked to sign an Informed Consent Form. Participants were then notified that they would each receive a complimentary Robotic Arm Trainer [7]. No other form of compensation was provided.

A pre-test questionnaire was distributed that gathered relevant user background information. Through this questionnaire, data related to participant demographics, education, computer experience, mechanical experience, and general attitudes relating to the use of technology were obtained.

Next, an OWI Robotic Arm Trainer and Robotic Arm PC Interface Kit [7] were distributed to each participant. A Usability Evaluation Workbook facilitated the sequencing of usability tasks. Tasks were presented to participants on separate workbook pages containing a start state, graphic image, instructions for task completion, and comment section. Each participant's time on task was recorded by this researcher through the use of a PC Interface Usability Task Sheet. Error rates and participant requests for assistance were also recorded.

At the conclusion of the study, student perceptions of their learning experience were collected through a post-test questionnaire. The questionnaire was based on a five-point rating scale (1, very dissatisfied to 5, very satisfied).

A second questionnaire measured user satisfaction in relation to the usability of the OWI Robotic Arm Trainer and Robotic Arm PC Interface Kit [7]. The questionnaire was based on a Likert-type scale where a rating of 1 represented the most negative response and 5 represented the most positive response.

Analysis

Qualitative data resulted from this researcher's observations of participant accuracy, speed, and recall. Additional data was gathered through the use of open-ended interview questions and questionnaires. Statistical percentages represented the mean extent to which each task and goal was completed. Individual criteria for success included an anticipated total time for task completion. Through this method, maximum time limits were established for groups of tasks. Overall success was determined according to the following criteria and scores:

- **Goal 1:** Tasks for Hardware and Software Setup
  Time on task = 5 minutes upward limit 10 minutes
  Assists = 0
  Task completion = all
- **Goal 2:** Tasks for Programming the Robotic Arm
  Time on task = 15 minutes upward limit 30 minutes
  Assists = 0
  Task completion = all
- **Goal 3:** Robot Trial Tasks
  Time on task = 20 minutes upward limit 30 minutes
  Assists = 0
  Task completion = all

A task completion score of 100% was awarded for each task that a participant completed without assistance from the researcher [see Tables 1, 2, & 3]. A reduction of 5% was applied to this score if the participant became unable to complete the task. A deduction of 10% was imposed for each task that the participant completed incorrectly. Although initial errors were noted, point reductions were not assigned by this researcher until each participant had indicated that he/she had completed the task. This method allowed participants to conduct a trial and error process without penalty.

Table 1 - Goal 1: Tasks for Hardware and Software Setup

Task	Goal
1	Install the software and troubleshoot if necessary.
2	Connect the printer cable to the laptop parallel port.
3	Connect the printer cable to the parallel port on the OWI PC Interface.
4	Disconnect the control box from the robotic arm.
5	Connect the PC Interface to the robotic arm.
6	Locate the Off / On Switch on the PC Interface. Verify that the switch is in the OFF position.
7	Uninstall the software application.

Table 2 - Goal 2: Tasks for Programming the Robotic Arm

Task	Goal
1	Reinstall the PC Interface software. Click on the robot icon to launch the program.
2	Use the Setup Port menu command to establish communication between the laptop and robotic arm.
3	Access the main window and the program window. Use the File menu to start a new program.
4	Send one direct command to the robotic arm.
5	Use the PC Interface to create and save a script file containing 10 different commands.
6	Use a saved file to activate the robotic arm.
7	Terminate the program and pause the robotic arm.

Table 3 – Goal 3: Robot Trial Tasks

Task	Goal
1	Access the main window and the program window then use the File menu to start a new program.
2	Direct the robotic arm to stack three wooden children's blocks in order to spell out a word.
3	Use the PC Interface to save the script file.
4	Launch a saved file to activate the robotic arm.
5	Terminate the program and pause the robotic arm

A goal achievement score of 100% was awarded to participants who completed all of the required tasks within the established time limits [see Tables 1, 2, & 3]. A reduction of 5% was applied to the goal achievement score of those who were not able to complete their tasks between the minimum and upward time limits. A 5% reduction was also applied to the participant's score for each task falling outside of the time limit range. Score reductions that met or exceeded a total of minus 100% resulted in a score of zero for goal achievement.

The International Organization for Standardization (ISO) [3] defines usability as the extent to which a product can be employed by users in order to achieve goals with effectiveness, efficiency, and satisfaction in a specified context of use. Usability testing is the measurement of ease of use of a product or piece of software.

In order to determine the effectiveness of the OWI PC Interface Kit [7] and software, data related to each participant's ability to complete a series of given tasks was gathered. These data were then compiled, and the results reported as the usability task completion rate [see Appendixes A, B, and C]. The extent to which each task was completed on time was reported as the goal achievement rate. Since participants were not provided with assistance during the testing period, the number of errors was recorded. Efficiency was reported through a variety of statistics. The mean time it had taken each participant to complete a given series of tasks was reported as the time on task. The task completion rate was divided by the mean time on task and reported as a participant's completion rate efficiency. The participant's goal achievement rate efficiency was obtained by dividing the goal achievement rate by the mean time on task.

User satisfaction was measured at the conclusion of the session. Data related to each participant's reaction to the software, system capabilities, and overall reaction to the usability test was also gathered.

RESULTS

Participants were able to successfully install the OWI PC Interface software and connect the hardware in a mean time of 11.1 minutes [see Appendix A]. Their first performance goal consisted of a series of seven tasks [see Table 1]. The mean extent to which all three individuals completely and correctly achieved this goal was 71%. The overall task completion rate was 100% for two individuals and 95% for the third participant.

The low score obtained by the third user was the result of an unanticipated hardware problem. After successfully installing the software, the participant was prompted to restart the laptop computer. The laptop froze on startup, causing the participant to seek information through the use of the instruction booklet. An additional error surfaced on startup that was the result of the third participant's inability to locate the manual on/off switch on the PC Interface circuit board.

The total time required for individuals to assemble the hardware and setup the software varied from 8.2 to 13.9 minutes, with only the third participant finishing before the upward time limit of ten minutes had expired. There were a total of eight references to the instructional booklet as users became uncertain of a part placement or sought clarification regarding a task.

In order to complete Goal 2, participants were required to reinstall the software and then establish communication between the computer and robotic arm [see Table 2]. The mean total time for completing this goal was 25.1 minutes while the group mean time on task was 3.6 minutes [see Appendix B]. In task three, participants were asked to access the main program window and program a sting of commands. All three participants successfully completed this task by launching the program through the use of the desktop icon. Individual scores for time on this individual task reflected 7.12 minutes, 5.17 minutes, and 6.11 minutes respectively.

Difficulties arose regarding each participant's ability to establish communication through the software's Setup Port command. The time spent on this task by participant one was 9.03 minutes while participant three finished in 8.03 minutes. Participant one encountered the most difficulties with this task. This individual committed four errors and referenced the instructional booklet a total of five times. In contrast, the second participant was able to establish communication between the computer and robotic arm after a total of only 0.42 seconds.

Task five required participants to create a script file containing any 10 commands and save it to the computer desktop [see Table 2]. Each participant was able to locate the appropriate command buttons on the user interface. The time on task for participant one was 13.03 minutes. The additional time required by this individual was due to user error. Twenty-three commands were programmed instead of the 10 that were requested. Participant two was able to program the 10 commands in 4.08 minutes, while participant three had finished after 6.59 minutes.

The purpose of Goal 3 was to test each participant's ability to recall the steps used for automating the robotic arm through the use of a saved file [see Table 3]. In task two, individuals were requested to program the robotic arm to stack three children's wooden blocks in as little time as possible while spelling any three letter word. This program was then saved and re-launched through the software interface. A minimum time allotment of twenty minutes was established and the mean time spent by participants for completing this goal was 11.0 minutes [see Appendix C]. The total times for participants one and two were 14.8 and 13.9 minutes respectively while participant three was able to complete the goal in a total of 4.3 minutes. There were no errors or references to the instructional booklet made by participants two and three. Participant one was unable to recall the steps used in accessing a saved file for automating the robotic arm. The goal and task completion rates for all three users resulted in scores of 100%. The group mean goal achievement efficiency was 60% while the task completion rate efficiency was 60% as well.

The results of the post-test questionnaire indicated that participants preferred to work in groups when setting up the PC Interface hardware and software [see Table 4]. In addition, a unanimous rating of "neutral" indicated that individuals were not satisfied with the instructional booklet. Ratings of "satisfied" and "very satisfied" demonstrated that participants enjoyed working with the software interface and manipulating the robotic arm. When describing their overall experiences, participants indicated that they had enjoyed working with the robotic arm and had rated the experience as "positive" and "very positive".

Table 4 – Learning Experience Results

Statement	Participant 1	Participant 2	Participant 3
Working alone when setting up the robotic arm	Neutral	Satisfied	Dissatisfied
Working alone when installing the software	Dissatisfied	Satisfied	Satisfied
Ability to use the software to create/save a program	Satisfied	Very Satisfied	Satisfied
Ability to operate the robotic arm in a precise manner	Satisfied	Very Satisfied	Satisfied
Ability to use the instructional booklet to troubleshoot problems	Neutral	Neutral	Neutral
Overall, how would you feel about your experience?	Positive	Very Positive	Positive

A Likert-type rating scale was used to gather data relating to user satisfaction and participant perceptions of the OWI Robotic Arm PC Interface software [see Table 5]. Research findings revealed that the participant's overall reaction to the software was positive as demonstrated by a mean score of 19. Two participants responded that the software was easy and satisfying to use while the third rated it as difficult and frustrating. The mean score for screen display was 13, which was just above average. Users returned a neutral rating relating to their ability to read the characters on the screen and were confused by the organization of information. Software error messages were considered unhelpful, and the prompts for input were perplexing. Scores of 17, 16, and 12 in the Learning category indicated that the participants were able to master the software after a trial and error period. All three participants perceived that software speed was adequate and reliable. The ability to correct mistakes received a mean score of 10, indicating that they were not satisfied with the system capabilities.

Table 5 – User Satisfaction Results

Participant	Software (30)	Screen (20)	Terminology (30)	Learning (30)	System (20)
1	13	15	12	17	9
2	23	13	12	16	10
3	21	10	14	12	12
Mean	19	13	13	15	10
Std. Dev.	5.3	2.5	1.2	2.6	1.5
Min.	13	10	12	12	9
Max.	23	15	14	17	12

DISCUSSION

Although the participants in this study completed all of the required tasks, some software design features did not work as intended with this sample of the population. A high level of frustration was observed when individuals were unable to locate adequate help files. These resources were missing from the software's dropdown menu and were only provided on a limited basis through the instructional booklet.

The ability to establish communication between the laptop and robotic arm was the most difficult task for participants to complete. Once connected, the robotic arm became active and the wrist rotated through its full range of motion. Since the robotic arm was composed of a medium weight plastic material, user anxiety resulted when one participant had been unable to locate the PC Interface off/on switch to stop the arm.

Although each of the participants had experienced some level of difficulty when setting up the laptop and robotic arm, their overall perceptions of the experience changed after using the software. During the post-test interview, participants reported that they possessed a feeling of satisfaction and pride in their ability to program the robotic arm. They enjoyed seeing their robotic arm run autonomously at the conclusion of the study. All three individuals were able to recall most of the procedures for programming the software and only one was unable to launch the saved file on the first attempt.

CONCLUSION AND FUTURE WORK

While further research is required, the results of this usability study demonstrate how the lack of detailed documentation can significantly impact a product's usability. Participants commented that they "had to learn things on their own" and that they "felt out of control when setting up the hardware and software". Research results verified that the learnability of the product had been affected since the participant's perception of ease of learning was rated poorly on the user satisfaction and post-test questionnaires.

The software used in this study has the potential for enabling educators to master computer programming concepts. The availability of a revised instructional booklet and the development of electronic help files are necessary before recommending this product for an online course in robotics and automation. It is recommended that this product be used in a graduate level course that meets on-campus. The majority of anxiety and frustration that were associated with the setup of this product would be alleviated if the participants had been provided with access to computers that were pre-loaded with the software and connected to a parallel port in advance. Students would have the ability to launch the software and connect their robotic arm to the printer cable. The course instructor would then be available for troubleshooting technological problems.

This investigation concluded research into the suitability of the OWI Robotic Arm PC Interface for use with K-12 educators having no prior computer programming experience. Future directions for research include the usability testing of additional robotics technology products and the pilot testing of instructional materials that can be integrated into online courses.

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Appendix A – Goal 1: Tasks for Hardware and Software Setup

Participant	Task Completion Rate (%)	Goal Achievement Rate (%)	Mean Time on Task (min)	Total Goal Time (min)	Task Completion Rate / Time on Task (%)*	Goal Achievement Rate / Time on Task (%)**	User Errors	References to Documents (Assists)
1	100.0	90.0	1.6	11.1	62	56	1.0	4.0
2	100.0	100.0	1.4	13.9	71	71	0.0	1.0
3	95.0	95.0	1.2	8.2	79	79	2.0	3.0
Group Mean	98.3	95.0	1.4	11.1	71	69	1.0	2.7
Std. Dev.	2.9	5.0	0.2	2.9	8.5	11.7	1.0	1.5
Min.	95.0	90.0	1.2	8.2	62	56	0.0	1.0
Max.	100.0	100.0	1.6	13.9	79	79	2.0	4.0

*Results in task completion rate efficiency **Results in goal achievement efficiency

Appendix B – Goal 2: Tasks for Programming the Robotic Arm

Participant	Task Completion Rate (%)	Goal Achievement Rate (%)	Mean Time on Task (min)	Total Goal Time (min)	Task Completion Rate / Time on Task (%)*	Goal Achievement Rate / Time on Task (%)**	User Errors	References to Documents (Assists)
1	100.0	85.0	4.8	33.4	21	18	4.0	5.0
2	100.0	100.0	2.0	13.9	50	50	1.0	2.0
3	100.0	95.0	4.0	28.0	25	24	1.0	2.0
Group Mean	100.0	93.3	3.6	25.1	32	31	2.0	3.0
Std. Dev.	0.0	7.6	1.4	10.1	15.7	17.0	1.7	1.7
Min.	100.0	100.0	2.0	13.9	21	18	1.0	2.0
Max.	100.0	95.0	4.8	33.4	50	50	4.0	5.0

*Results in task completion rate efficiency **Results in goal achievement efficiency

Appendix C – Goal 3: Robot Trial Tasks

Participant	Task Completion Rate (%)	Goal Achievement Rate (%)	Mean Time on Task (min)	Total Goal Time (min)	Task Completion Rate / Time on Task (%)*	Goal Achievement Rate / Time on Task (%)**	User Errors	References to Documents (Assists)
1	100.0	100.0	3.0	14.8	33	33	3.0	2.0
2	100.0	100.0	2.7	13.9	37	37	0.0	0.0
3	100.0	100.0	0.9	4.3	111	111	0.0	0.0
Group Mean	100.0	100.0	2.2	11.0	60	60	1.0	0.7
Std. Dev.	0.0	0.0	1.1	5.8	44	44	1.7	1.2
Min.	100.0	100.0	0.9	4.3	33	33	0.0	0.0
Max.	100.0	100.0	3.0	14.8	111	111	3.0	2.0

*Results in task completion rate efficiency **Results in goal achievement efficiency