2004

Robotics Technologies for K-8 Educators: A Semiotic Approach for Instructional Design

Antoinette P. Bruciati
Sacred Heart University

Robotics Technologies for K-8 Educators: A Semiotic Approach for Instructional Design

Antoinette P. BRUCIATI
Education Department, Sacred Heart University
Stamford, CT 06907, USA

ABSTRACT

Robotics engineering courses have provided undergraduate computer science students with opportunities for designing and programming simulations of robotic tasks. In contrast, many teacher preparation programs have lacked courses in this area. Educators who have not gained a conceptual understanding of computer programming may not possess the skills that would have enabled them to successfully integrate robotics technologies into their K-8 curriculum.

Recent technological advances have provided a viable means of approaching this problem. Several icon-orientated robotics technologies have been identified that allow educators to master computer programming concepts through a simplified graphical user interface (GUI) design.

This investigation addressed the need for a graduate level course that would enable K-8 educators to receive professional development training in the area of robotics technologies. An examination of the current best practices in robotics education has been conducted. Software usability and human factors have been discussed in terms of the suitability of commercially available robotics products for educators having no prior computer programming experience. Suggestions for curricular design and future research in the area of robotics were offered.

Keywords: Robotics Technologies, Standards, K-8 Education, Instructional Design, Semiotics.

INTRODUCTION

Over the past ten years, robotics technologies have become the focus of many research groups [1]. Since 1997, the National Aeronautics and Space Administration (NASA) has made it possible to command simulated missions of a Martian rover via the Internet [25]. The Massachusetts Institute of Technology (MIT) Media Lab has been developing a robotic computer prototype that will be capable of recognizing and physically responding to human socio-emotive cues [21]. Intelligent robotic toys have recently appeared in the consumer marketplace [23] and the presence of service robots is becoming more commonplace in today's society [13].

It has been estimated that more than half of all students who enter grade 9 will go directly into the workforce after graduating from high school [29]. In order to insure that students are prepared to enter the 21st century workforce, educators must be equipped to teach a new technological and vocational curriculum. Through this investigation, the following research questions will be addressed:

- What best practices in robotics education exist at the university level?
- What role can robotics technologies play in the K-8 curriculum?
- What robotic technologies are available for educators having no prior computer programming experience?
- How should instruction in robotics technologies for K-8 educators be designed?

CURRENT PRACTICES

Computer science is an intellectually demanding discipline that requires a mastery of sophisticated programming languages. The programming tasks that computer science students typically encounter include the use of procedures, variables, subroutines and augments. Many institutions of higher learning routinely incorporate the use of programmable robotic kits in their computer science curricula [11] since these technologies can be adapted to accept commands that are created through a variety of high level programming languages [9].

Hands on robotics education courses exist at many institutions of higher learning including; Carnegie Mellon University [28], Villanova University [11], and Swarthmore College [18]. These courses provide undergraduate engineering and computer science students with opportunities for designing and programming simulations of robotic tasks. Educational objectives are mastered through the use of open-ended laboratory experiences and the guidance of knowledgeable teams of faculty and teaching assistants. In order to meet the educational goals of these courses, students are expected to have a prior knowledge of ADA, Java, C++ or other high-level computer programming languages [11].

ROBOTICS AND ACTIVE LEARNING

The primary role of the teacher is to nurture a student's ability to acquire knowledge. Robotic technologies have the potential for facilitating active learning in a K-8 curriculum. They can be used by students as experiential instruments for exploring the curriculum in the context of the outside world. Many teacher preparation programs lack courses that offer a methodology for integrating robotics into the K-8 curriculum since state regulations do not require that educators participate in professional development training in this area [6]. This situation may present a problem for many K-8 educators since the lack of training may prevent them from integrating robotics technologies into lesson plans that are developmentally appropriate for their students.

HUMAN FACTORS AND INTERFACE DESIGN

Human learning, problem solving and memory can be greatly influenced by meaningful structure [30]. The instructional design of courses that include the use of cognitive strategies will support a learner's interaction with course content and promote meaningful and sequential cognitive activity [15]. When developing learning activities in the area of robotics technologies, instructional designers must give greater consideration to the role and limitations of a learner's working memory in order to optimize a student's cognitive processing load [35]. Cognitive load is defined as the amount of mental effort that learners are required to expend while processing information [10]. Learners facilitate the transfer and organization of information by placing it in a context of personal relevance [17]. Information that is organized through its association with prior knowledge will be easier for the learner to recall from long-term memory. Instruction that effectively presents information to working memory has a positive impact on a learner's ability to store and retrieve knowledge from long-term memory [35].

Individuals incorporate a variety of cognitive strategies when achieving desired goals. A software interface may include labels in the form of graphic icons for display-based environments or digital text for command based systems [32]. Users with limited proficiency in the use of technology become overwhelmed and confused by the complexity of a graphical user interface (GUI). Besides cognitive aspects, psychological, developmental and organizational elements may impact the usability of a software product [3]. These elements are typically reflected in the nature of tasks that users are expected to perform.

SEMIOTICS AND SYMBOLS

The field of semiotics represents a range of studies in art, literature, anthropology and the mass media. Semiotics is defined as the study of how people use signs, graphic symbols and icons for nonverbal communication [8]. The careful, systematic application of graphic symbols and icons is crucial to the success of interface design [30].

Several symbol-based robotics software products are commercially available that are based on the use of icons. These software products allow educators to master computer programming concepts through a simplified GUI design. An icon is a symbol in the form of a graphical image that represents a computer function or control [12]. Icon-specific guidelines suggest that objects or actions be represented in a familiar or recognizable manner [30]. Computer displays that incorporate easily recognizable icons will facilitate the ability of a user to successfully complete a task [26].

ICON-ORIENTATED ROBOTICS TECHNOLOGIES

The following section offers a synthesis of robotics technologies that are based on an icon-orientated programming environment. These software applications enable educators to program robotic commands without difficulty since they incorporate the use of images and icons for generating lines of programming code.

OWI Robotic Arm Trainer

The OWI Robotic Arm Trainer [27] is a robotics technology product that is capable of five axes of motion. This product has the ability to lift approximately 4.6 ounces. It is made from lightweight plastic and available in kit form. Motion is achieved through the use of five direct current motors that are wired to a central control unit. The arm can be manually directed through a five-switch controller or can be programmed to act autonomously through a supplemental IBM™ PC interface. The Robotic Arm Trainer can be assembled using simple hand tools and is powered through the use of four D cell batteries.

The PC interface software requires a computer capable of running either DOS or Windows® 95/98 based programs [19, 20]. The robotic arm interface kit includes an external interface card that connects to the computer's parallel printer port. The software interface allows an individual to program, edit, save and download coded instructions. The screen display includes a graphic image and set of labels that correspond to particular robotic arm actions. The interface permits real time control of the robotic arm through an icon-based, interactive scriptwriter. Menus are labeled in familiar terms including; File, Edit, View and Help. Selecting the File menu will result in a drop down list allowing a user to create a new program, open a program, save a program, or print. The interface design is based on a common terminology that enables the user to successfully discover and recall the correct action sequences [32]. A user may program a script containing up to ninety-nine individual robotic arm functions. The program can then be saved and loaded from a floppy disk or the computer's hard drive. Script files can be programmed to replay automatically and are useful for demonstrating computer controlled automation and animatronics. In addition to using the Windows® program, the robotic arm can also be programmed through the use of either the BASIC or QBASIC programming languages.

Lego Mindstorms

The Lego Mindstorms Robotic Invention System allows developers to design, program and implement a variety of entry-level robots. These robots interact with their environments through the use of light, touch and sound sensors [33]. The primary component of this system is a RCX programmable brick containing three input and output ports. Ports are attached to a Hitachi H8/3292 microcontroller [9]. Programming is accomplished through the use of the Lego RCX code or Lego MindScript. Lego RCX code is based on the LOGO programming language and the Windows®, icon-based programming environment. Through the use of the software and a mouse, graphic representations of programming code can be dragged and assembled into strings at the center of the computer screen. Several additional high level programming languages have been successfully used with this system and include; NQC, Visual Basic, ADA, Java and C++.

In addition to the microprocessor, each robotics kit contains an assortment of body parts, motors and sensors. An infrared (IR) transmitter allows the program code to be transferred from the PC to the microprocessor. The use of the IR tower enables the robot to remain autonomous during its operation. The RCX has the capacity for exchanging transmissions with other RCX microprocessors or a personal computer (PC).

LEGO Dacta Robolab

The Lego Robolab System is an educational version of the Mindstorms product [34]. Through the use of the LabVIEW software, students may choose between two levels of programming that include RCX Pilot or Inventor. Each level is divided into a series of four sub levels that present the learner with a logical progression of difficulty. The GUI is similar to the one used in the Mindstorms system. Strings of icon commands are assembled on the computer screen and represent the action of the RCX inputs and outputs. The Robolab System is offered in a variety of configurations that are suitable for students of different ages and skill levels. Different themed robotic sets are available that include an amusement park, cities or transportation.

TechnoK'NEX Computer Control System

K'NEX Education [16] offers a series of curriculum units that can be used with the TechnoK'NEX Computer Control System. The system is based on the programmable Leonardo® interface and is similar in design to the programmable bricks offered by competitors. Up to six procedures can be downloaded to the Leonardo® interface. Each interface communicates through radio frequency transmissions containing a separate identification number. Through this process up to 95 different units can operate in the same vicinity without interference.

Robots can be programmed through the use of a simplified icon-based software language. Four levels of computer programming can be integrated into a variety of interdisciplinary lesson plans. Direct control allows users to operate the robot through the computer while automatic control enables the robot to run independently through programmed procedures. The third programming level allows users to integrate sensor feedback and interactive control. Finally, through collaborative control two or more robots can be programmed to communicate through wireless technologies.

INSTRUCTIONAL DESIGN

The success of technology in facilitating a student's higher order thinking skills is dependent on the use of an effective instructional design [14]. Instructional design is defined as a systematic process through which principles of learning and instruction are translated into plans for educational materials and procedures [31]. Benefits of the instructional design process include congruence among objectives, activities and assessment protocols along with support for the development of alternate delivery systems.

Instructional designers are faced with the challenge of determining where and when to apply technological bells and whistles so they do not hinder an individual's ability to acquire knowledge [2, 7]. Decisions relating to the integration of robotics technologies into classroom instruction should not be based on the use of technology for its own sake.

DESIGNING THE ROBOTICS CURRICULUM

The following section offers practical suggestions that can direct the development of a course in robotics technologies. Guiding questions that can be used as a framework include:

- What is the instructional problem?
- What curricular standards align with the problem?
- Are there any learner characteristics that must be considered when designing the course?
- What content should be included in the course?
- What are the performance standards for the course?
- What tasks should be used to guide the learning process?
- How can the performance standards be assessed?
- How can assessment data be gathered and reported?
- How can the course be improved?

The term *curriculum* refers to the elements within a course or program [22]. These elements include content, standards, skills and learning outcomes. Prior to designing a curriculum, an instructional problem must be identified that results from a needs assessment. Instructional goals are then recommended and aligned with state or national curricular standards. Standards establish guidelines that suggest what students should know be able to do [4].

In the following example, a needs assessment has revealed that there is a call for for technologically proficient students who are ready to enter the workforce. The development of a course in robotics technologies for K-8 educators has been proposed as a possible solution to this problem. One of the content standards that have been aligned with the course requires that educators develop classroom strategies that foster the integration of technology across the curriculum [5].

The next step in curricular design would be to conduct a learner analysis in order to determine if there are any characteristics that would influence decisions relating to the development of the course. Since the learners in this example have previously been described as K-8 educators, course content must be included that will provide background information and support the investigation of robotics technologies. Related sub-topics could include the history of robotics along with the methods for the development of robotics related lesson plans and curricular materials.

Since the K-8 educators in this example have no prior experience in computer programming, one approach for guiding the learning process would be to structure learning tasks around the use of an icon-orientated programming environment. This software would meet the needs of the target audience since its use would not have required that the educators master a high-level computer programming language.

Prior to determining which icon-orientated programming environments should be incorporated into the course, an expert review of robotics technologies must be completed. Expert reviews are essential for identifying problems and providing recommendations [30]. This preliminary step is important for determining which robotics technologies would be most suitable for use. Through usability testing, the use of the software in a real world setting can be assessed. A variety of expert-review methods can be employed for evaluating the usability of robotics technologies. These include:

- Heuristic evaluation;
- Guidelines review;
- Consistency inspection;
- Cognitive walkthrough; and
- Formal usability inspection.

Assessment must be based on the use of assignments that are aligned with competency-based performance standards. Learning outcomes can be included that would signal an educator's level of academic achievement and proficiency in course content knowledge, essential skills and understandings [4, 5]. For example, educators could be required to demonstrate their understanding of emerging technologies in the area of robotics. This competency can be assessed through a variety of learning outcomes that include; the use of the Internet for locating information about the topic of robotics, a descriptive essay, a slide show presentation, or a product review related to a robotics product.

Data that relates to an educator's ability to master course competencies must be gathered and reported. During the last decade, teacher preparation programs have routinely incorporated the use of portfolios as one method for assessing student learning and professional development. The principal features of portfolios include their capacity for capturing a learner's achievements under authentic conditions and their potential for providing a means whereby those achievements can be documented. Digital portfolios have the potential for incorporating a wide range of resources that include academic accomplishments in the form of classroom assignments, evaluations and other computer based projects. A digital portfolio is defined as a multimedia collection of student work [24]. Through the use of a digital portfolio, instructors and administrators can be equipped with a tool for evaluating an educator's professional development over time.

CONCLUSION

Robotics technologies hold a promising future for educational applications. These resources provide students with opportunities for assimilating information from multiple disciplines and connecting knowledge to real world situations. Through a semiotic approach for instructional design, robotics theory, design and basic programming skills can be easily integrated into the K-8 curriculum.

Courses in robotics can ultimately produce educators who are adept at applied technologies. Although some individuals may wish to integrate robotics into their classroom curricula, the relationship between algorithms and computing agents is beyond the grasp of many educators and their students. The use of icon-based programming languages can meet the needs of beginning programmers. However, if adequate training is not available, educators may be reluctant to experiment independently.

Many icon based robotics technology products are commercially available that are suitable for utilization in a graduate teacher preparation program. Recommendations for future research in this area include the usability testing of the icon-based robotics technologies that have been described.

REFERENCES

[1] B. Adams, C. Breazeal, R. Brooks, & B. Scassalatti, "Humanoid Robots: A New Kind of Tool" **IEEE Intelligent Systems**, Vol. 15, No. 4, 2001, pp. 25-31.

[2] B. Beccue, J. Vila, & L.K. Whitley, "The Effects of Adding Audio Instructions to a Multimedia Computer-Based Training Environment", **Journal of Educational Multimedia and Hypermedia**, Vol. 10, No. 1, 2001, pp. 47-67.

[3] B. Bombsdorf, & G. Szwillus, "From Task to Dialogue: Task-Based User Interface Design", **In Proceedings of the Conference on CHI 98 Summary: Human Factors in Computing Systems. Los Angeles, California**, 1998, p. 201. New York, NY: ACM Press.

[4] R.W. Bybee, & S. Loucks-Horsley, "Standards as a Catalyst for Change in Technology Education", **Technology Teacher**, Vol. 59, No. 5, 2000, pp. 14-17.

[5] Connecticut State Department of Education, **Connecticut Teacher Technology Competencies**. Office of Grant Programs and Technology, Division of School Improvement. Pub. 2001. Retrieved May 8, 2003, from: http://www.state.ct.us/sde/dsi/technology/CTTCt.pdf.

[6] Connecticut State Department of Education, **The Connecticut Framework: K-12 Curricular Goals and Standards – 1998.** Bureau of Curriculum and Instruction. Pub. 1998. Retrieved June 14, 2003, from: http://www.state.ct.us/sde/dtl/curriculum/currkey3.htm.

[7] G.V. Davidson-Shivers, B. Nowlin, & M. Lanouette, "Do Multimedia Lesson Structure and Learning Styles Influence Undergraduate Writing Performance?", **College Student Journal,** Vol. 36, No. 1, pp. 20-31.

[8] U. Eco, **A Theory of Semiotics,** Bloomington, IN: Indiana University Press. Pub., 1976.

[9] B. Fagin, "Using ADA-Based Robotics to Teach Computer Science", **In Proceedings of the Fifth Annual Conference on Innovation and Technology in Computer Science Education** (ITiCSE 2000), New York, NY: The Association for Computing Machinery, 2000, 148-151.

[10] S. Feinberg, & M. Murphy, (2000). "Applying Cognitive Load Theory to the Design of Web-Based Instruction", **In Proceedings of IEEE Professional Communication Society International Professional Communication Conference and Proceedings of the 18th annual ACM International Conference on Computer Documentation: Technology & Teamwork.** Cambridge, Massachusetts. Piscataway, NJ: IEEE, 2000, pp. 353-360.

[11] M. Goldweber, C. Congdon, B. Fagin, D. Hwang, & F. Klassner, "The Use of Robots in the Undergraduate Curriculum: Experience Reports", **Technical Symposium on Computer Science Education,** ACM Press New York, NY, 2001, pp. 404-405.

[12] W. Horton, **The Icon Book: Visual Symbols for Computer Systems and Documentation**. Canada: John Wiley & Sons. Pub., 1994.

[13] iRobot Corporation, **Roomba**. Burlington: MA, 2004. Retrieved March 6, 2004 from: http://www.irobot.com/home/default.asp.

[14] H. Kanuka, & T. Anderson, "Using Constructivism in Technology-Mediated Learning: Constructing Order Out of the Chaos in the Literature", **Radical Pedagogy**, Vol. 1, No. 2. Retrieved May 20, 2003 from: http://www.athabascau.ca/html/staff/academic/terrya.html

[15] A. King, "Structuring Peer Interaction to Promote High Level Cognitive Processing", **Theory Into Practice**, Vol. 42, No. 1, 2002, pp. 33-39.

[16] K'NEX Industries, Inc., **TechnoK'NEX Computer Control System**, K'NEX Education, Hatfield, PA, 2001. Retrieved June 10, 2003 from: http://www.knexeducation.com.

[17] K. Mann, "Thinking About Learning: Implications for Principle-Based Professional Education", **The Journal of Continuing Education in the Health Professions**, Vol. 22, No. 2, 2002, pp. 69-76.

[18] B.A. Maxwell, & L.A. Meeden, "Integrating Robotics Research with Undergraduate Education", **IEEE Intelligent Systems,** Vol. 15, No. 6, 2000, pp. 22-27.

[19] Microsoft Corporation, [computer software] **Microsoft® Windows® 95**, Redmond: Washington, 1987-2001.

[20] Microsoft Corporation, [computer software] **Microsoft® Windows® 98**, Redmond: Washington, 1987-2001.

[21] Massachusetts Institute of Technology Media Lab. **Robotic Life: RoCo**, 2002. Retrieved March 6, 2004 from: http://robotic.media.mit.edu/projects/RoCo.html.

[22] G.R. Morrison, S.M. Ross, & J.E. Kemp, **Designing Effective Instruction**, (3rd ed), New York: John Wiley & Sons. Pub., 2001.

[23] R.R. Murphy, "Robots and Education", **Intelligent Systems IEEE**, Vol. 15, No. 6, 2000, pp. 14 -15.

[24] D. Niguidula, "The Digital Portfolio: A Versatile Multimedia Tool", **Principal**, Vol. 82, No. 3, 2003, pp. 56-7.

[25] National Aeronautics and Space Administration, **Field Integrated Design & Operations Rover**. 2004. Jet Propulsion Laboratory: California Institute of Technology. Retrieved March 6, 2004 from: http://fido.jpl.nasa.gov/.

[26] J. Nielsen, "Are Users Stupid?" **Alertbox: February 4, 2001**. Retrieved February 5, 2003 from: http://www.useit.com/alertbox/20010204.html.

[27] Robotikits Direct, **OWI Robotic Arm Trainer**, Carson: CA, 2002, Retrieved February 5, 2003 from: http://robotikitsdirect.com.

[28] M. Rosenblatt, & C. Choset, "Designing and Implementing Hands-On Robotics Labs", **IEEE Intelligent Systems**, Vol. 15, No. 6, 2000, pp. 32-39.

[29] D. Ross, & P. Nelson, "Eves Government Invests $90 Million to Improve Technological Education", **Ministry of Education: Government of Ontario Press Releases**. Retrieved June 10, 2003, from: http://www.newswire.ca/.

[30] B. Shneiderman, **Designing the User Interface: Strategies for Effective Human-Computer Interaction.** Reading, Mass: Addison-Wesley Longman, Pub., 1998.

[31] P.L. Smith, & T.J. Ragan, **Instructional Design,** (2nd ed). New York: John Wiley & Sons. Pub., 2001.

[32] R. Soto, "Learning and Performing by Exploration: Label Quality Measured by Latent Semantic Analysis", **In Proceedings of the CHI 99 Conference on Human Factors in Computing Systems: the CHI is the Limit.** Pittsburgh, Pennsylvania, 1999, pp. 418-425, New York, NY: ACM Press.

[33] The Lego Group, [computer software] **Lego Mindstorms**: **Robotics Invention System 2.0**, Lego Educational Division, Pittsburg: KS, 2003. Retrieved January 29, 2003, from: http://mindstorms.lego.com/eng/products/ris/ index. asp.

[34] The Lego Group, [computer software] **Robolab: Lego Mindstorms Sets for Schools**, Lego Educational Division, Pittsburg: KS, 2003. Retrieved January 29, 2003, from: http://www.lego.com/education/.

[35] J.E. Tuovinen, "Optimizing Student Cognitive Load in Computer Education", **In Proceedings of the on Australasian Computing Education Conference.** December 2000, SIGCSE: ACM Special Interest Group on Computer Science Education. Melbourne, Australia. pp. 235-241. New York: ACM Press.