The Challenge of Robotics Education in Science Museums

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Abstract

This paper provides an overview of the spectrum of robotics programs at the Israel National Museum of Science, Technology and Space (MadaTech), including exhibitions for the general public as well as educational activities for students, at the Museum's Gelfand Center for Model Building, Robotics & Communication. MadaTech's robotics programs aim to promote public understanding of science and engineering through the prism of robotics. In this paper, we present innovative robotics initiatives achieved through collaboration between MadaTech and the Technion, and heavily supported by the Ministry of Education and the Haifa Municipality. The initiatives evoked strong interest among broad and varied audiences. Modern intelligent robots, such as the Nao, Thespian, and Aibo, used by MadaTech, have proved their effectiveness as performance and program protagonists. From our experience, conventional robotics education through construction and programming robots can be significantly enriched by learning activities based on interaction with a robot, inquiry into analogies between biological and robotic systems, and rational combination of competitive with developmental activities.

Keywords: *Educational Robotics, Science Museum, Human-robot Interaction*

1. Introduction

Knowledge-based society places great emphasis on human development and social inclusion through informal science education, in which museums of science and technology play a central role. To maintain and promote that role in the digital age, science museums are seeking new ways to create ICT-based interactive exhibitions, to expose visitors to powerful technological innovations, and to offer educational activities to students in technology-enhanced environments. Alexander and Alexander [1] point out that museums often present technological systems as static artifacts, while "machinery is most meaningful to observers when it is in operation." Providing maintenance of machinery and its safe operation in a museum is a challenge, but the effort is justified. As noted by Hudson [2], "In today's world, a museum of science and technology which does not encourage its visitors to think of the human and social consequences of new developments, is acting in a singularly irresponsible and out-of-date fashion."

The rapidly growing field of educational robotics, with a significant impact on education in universities and schools, has recently arrived on the doorstep of science museums. Robotics has gained popularity in informal school education both in Israel and abroad, in the form of extra-curricular programs and robot competitions.

The literature discusses experiments of science museums in the use of robots as exhibits, as remote facilitators, and as entertaining guides. A Paro robot is designed and programmed to imitate a Greenland seal [3]. It is used at Stockholm's National Museum of Science and Technology to demonstrate human interaction with an animate. The study indicates that Paro positively impressed visitors, mainly because of its physical features and responses to sound, light, and tactile stimuli. Another example is the Personal Exploration Robot Rover [4], exhibited at five science museums in the US. This robotic exhibit served to demonstrate the role of rover missions in NASA's Mars Exploration Program, as well as robot autonomy. A study by All and Nourbakhsh [5] indicates that the learning process is at its most effective, when using a robot to illustrate the subject matter, and a human instructor, to provide the explanation.

There are examples in the literature of robots serving as guides, exhibit instructors, and for greeting and entertaining museum visitors [6, 7]. One such is a Docent robot, which guides tours at the Daejeon

Museum of Art. The 120cm (4′) tall robot stands roughly at eye-level with children, and provides information as it proceeds from one exhibit to another, before ending its tour at a large plasma display panel. It has already made the rounds at a number of museums, introducing children to works of art, as well as to Korea's robotics technology.

Many science museums now offer hands-on learning activities using robot kits. A breakthrough pioneering program, the Computer Clubhouse, began at the Boston Computer Museum [8], was adopted by other museums [9], providing a strong impetus for rapid dissemination of similar programs. In this program, robotics workshops are conducted for primary and junior high school students, using a PicoCricket kit.

This paper presents new robot exhibitions and educational programs developed at the Israel National Museum of Science, Technology and Space (MadaTech), in collaboration with the Technion. The programs aim to promote public understanding of robots, to motivate young people to study robotics, and to foster excellence in technology and science education. They cater to a broad array of school students in the Haifa area, throughout the north of Israel and nationwide.

This paper is organized as follows: Section 2 describes the growth of robotics exhibitions and activities at MadaTech; Section 3 presents the robot theatre program; Section 4 focuses on the OlympiYeda Annual Science Competition; and Section 5 discusses the latest initiatives at MadaTech.

2. Methods and activities

Robotics education activities at MadaTech began in 2000-2001, in the form of brief hands-on lab sessions conducted in a computer class, using Lego Mindstorms kits. In the ensuing years, a robotics workshop on road safety was developed, implemented and upgraded. At this workshop, students conducted experiments and performed robot projects pertaining to automatic traffic lights at road intersections, automatic barriers, autonomous vehicles, Mars exploration with a Pathfinder robot, a smart crane, and a line follower.

2003-2006, saw development at MadaTech, of the first interactive robot demonstrations for classes and the general public and the onset of robotics programs, including courses for technology teachers and workshops for junior high school students. In 2007, the MadaTech Gelfand Center for Model Building, Robotics & Communication was established, comprising two robotics laboratories--each equipped with a network of twelve computer workstations, robotics software and audio visual instrumentation; a demonstration hall and auxiliary facilities. In 2007-2009, the Center provided a wide spectrum of robotics activities, including robotics for school classes, semester- or year-long courses, training courses for kindergarten and elementary school teachers, programs for junior high school students from abroad, and specially-tailored lessons for girls, new immigrants and families. A mobile laboratory was created, facilitating robotics workshops for students in peripheral schools in northern Israel. In 2009, tens of thousands of school students and teachers participated in these robotics activities.

The year 2010 was dubbed by the Museum as the Year of Robotics. For the first time, both MadaTech's major thematic exhibition and its educational programs centered on the study of technology and engineering through robotics, "The Robot World: Scientific and Human Challenges." The core of the thematic exhibition was *Robot Zoo*, featuring a variety of computerized interactive mechanical models of animals, such as a chameleon, a rhino, a squid, a fly and more (Figure 1A). *Robot Zoo* was complemented by a number of state-of-the-art robots, presented in interactive demonstrations. They included humanoids, such as Nao (http://www.aldebaran-robotics.com/) and a RoboThespian (www.robothespian.com/), the robotic dog Aibo (http://support.sony-europe.com/aibo/index.asp) and more. The Exhibition, which also presented a variety of robots for military, industrial and domestic uses, loaned by governmental institutions and private companies (Figure 1B), was extremely popular, enjoying over 350,000 visitors.

MadaTech's major thematic exhibition and educational programs for 2011 are dedicated to the science of motion and sport. Robotics initiatives constitute an important part of these activities, facilitating demonstration of the laws of mechanics, perceptual and motor behavior concepts, and principles of locomotion.

A. B.

Figure 1. A. The robot giraffe; B. Autonomous guided vehicle

3. Results

3.1 Robot Theatre Performances for the Public

MadaTech's Robot Theatre Program follows on a long tradition of theatrical performances in science museums, as a way of effectively communicating science to the public. The initiative to introduce robot theatre to MadaTech is in line with pilot theatrical performances recently introduced into other museums [10, 11]. It was influenced by the following factors:

- Interactive presentations of the humanoid Nao robot, given by Aldebaran Robotics (France), at the Technion and at MadaTech, illustrated that Nao performances facilitate the introduction of robotics concepts to the public, in an exciting and attractive way. Consequently, the Museum ordered a number of Nao robots;
- During a 2009 visit to the new Korea Robot Land Theme Park in Incheon, we had the opportunity of learning from the interactive performances of another robot humanoid, Bioloid, presented by Robotis to *Robot Zoo* exhibition visitors. These performances, in which a human actor demonstrated the robot through interaction with young students, attracted great student interest and emotional involvement;
- MadaTech ordered a human-size robot, RoboThespian (www.robothespian.com), created to serve a robot theatre actor. The Museum also developed a short feature film, whose protagonists are, a human actress, Thespian and Nao robots and a virtual parrot. The film was shown to visitors as they entered the *Robot World* exhibition.

The robot theater performance developed at MadaTech, took the form of a series of theatrical pieces, in which a human actor, assisted by a technician, demonstrated three different robots: a Roomba vacuum cleaner, an Aibo robot dog and a Nao humanoid. The performance demonstrated basic concepts of robotics, while illustrating robot functionality and behavior repertoire. In presenting Roomba, the actor talked about service robots. He playfully demonstrated the robot in action and explained principles of sensing and communication. The public was able to interact with Roomba and observe its reactions to spreading waste and to coming up against a virtual wall in the robot workspace.

Aibo's presentation emphasized its advanced intelligence compared to the robotic models of animals at the *Robot Zoo* Exhibition. Aibo's different emotional reactions and capabilities of learning from interaction with the public were demonstrated (Figure 2A). The culmination of the robot theater performance was the Nao show (Figure 2B).

The show consisted of three parts: greetings, a Tai Chi exercise, and a dance in memory of Michael Jackson. Each part of the show demonstrated a different aspect of a Nao function and was used by the human actor to introduce and illustrate scientific, technological and social concepts. In the greeting part, the robot presented autonomous behaviors: standing-up, walking, gesturing and human-like speech.

A.

B.

Figure 2. A. The robot theatre B. Spectators at the performance

During the presentation, the actor introduced concepts such as stability, locomotion, and text-to-speech capability. In the Tai Chi exercise, the explanation was based on the use of two physics concepts: center of mass and equilibrium. Spectators were encouraged to practice Tai Chi along with the robot. They experienced the difficulty of maintaining their balance during the exercise and discovered that Nao performed better than did some of them! The Nao dance demonstrated the robot's ability to perform various movements and to synchronize motion with music. The accompanying explanation focused on an analysis of the robot's degrees of freedom used in dance movements. Spectators were asked to compare these to human degrees of freedom. The performances, given in a specially-arranged 100-seat amphitheater, attracted wide public interest, attended by most of the 350,000 *Robot World* Exhibition visitors.

A unique theatrical play, staged by MadaTech, along with the Haifa Symphony Orchestra, took place in Haifa, in December 2010. A scientific demonstration was combined with performance of well known classical music pieces. The three play protagonists were Albert Einstein (Dr. Ronen Mir), his wife Elsa (conductor Karin Ben-Yosef) and a Laboratory Assistant (Nao robot). Einstein introduced his discoveries, his Assistant performed demonstrations, while his wife expressed her impressions through music. The show aimed to attract and expose elementary school students to both science and music. The children were highly interested and emotionally involved throughout the interactive play (Figure 3).

Figure 3. The show's protagonists interacting with the audience

3.2. The OlympiYeda competition

The OlympiYeda ("Yeda" in Hebrew means "knowledge") is a nationwide annual competition in science and technology for 8th/9th graders, conducted by the MadaTech museum since 1989. Its objective is to foster excellence in science-technology education and interest to topical areas beyond the school curriculum. The topics of the 2010 and 2011 Olympiads were connected to robotics: “Scientific and Humane Challenges in the Robot World” and “Science of Motion and Sport”. Along these years the 4-stage outline of the competition remains the same:

1. Thousands of students from middle schools throughout Israel pass a test in general science, mathematics and spatial reasoning aimed to identify students who are capable of self-learning beyond the school curriculum.
2. The selected students by their own learn subjects related to the topic of interest, using the instructional materials supplied by the program. At the end of this stage they take an exam on the studied material.
3. The highest achieving students participate in the OlympiYeda summer camp. The program includes workshops, lectures, excursions, social events. The OlympiYeda students get opportunities to communicate with and learn from elder international students who participated in the Technion’s research programs. Two examples of such practices are the assistive robotics workshop conducted by two engineering students from the U.S.A. (Figure 4A) and the project presentation given by two senior high school students participated in the Technion Summer Research Program for Youth (Figure 4B).
4. The top 8 students participate in the final quiz in front of a live audience – their classmates, family members, and educators. Four winners of the quiz get scholarships for studies at the Technion.

A. B.

Figure 4. A. Assistive robotics workshop B. Technion CIM and robotics lab

4. Latest Initiatives

4.1 Workshop on learning by interaction with robotic animals (2010-2011)

The workshop was given to classes from nine Haifa elementary schools. A total of 300 third- and fourth- grade students participated in the basic (9 hours) or extended (18 hours) Workshop version, using the Lego We Do Education kit. Both Workshop versions comprised the following sessions:

- Robot introduction - students were exposed to different types of robots, through live demonstrations and videos;
- Experimental testing of pre-programmed robot behaviors - Each pair of students got a crocodile robot (equipped with an IR motion detector) and tested its responses to different "stimuli" movements around it (Figure 5A);
- Creation of new robot behavior - students programmed simple and reactive robot behaviors using graphical block language;
- Constructing, programming and testing a new robot - students constructed a dog robot (with a tilt sensor) and independently devised and tested its behavior.

The extended Workshop version included additional sessions:

- Robot motor and control systems - robotics concepts studied by analogy with biological systems;

- Creation of robot-robot interactions and video reports - students developed and implemented interactions between the crocodile and dog robots (Figure 5B). Video filming documented the interactions and explained the underlying technical solutions.

Top Workshop participants were chosen to present their projects and compete in the 2011 Regional Junior First Lego League *Body Forward* Festival, held at MadaTech.

A. B.

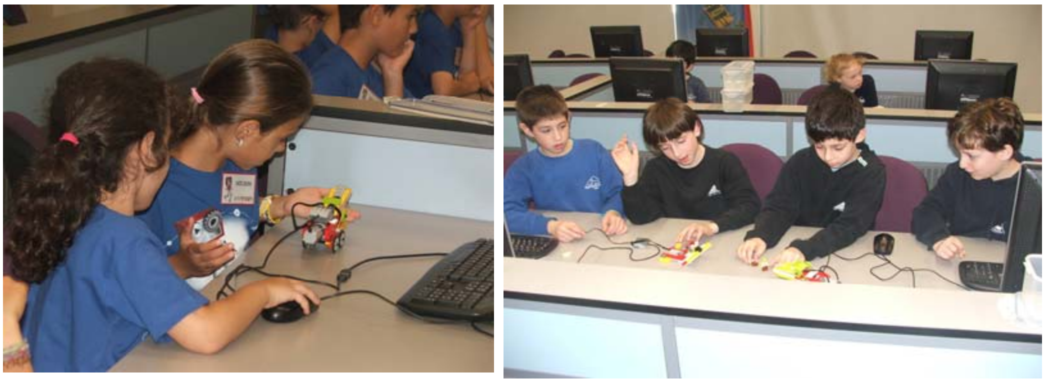

Figure 5. A. Inquiry into robot behaviors B. Creating robot-robot interactions

The workshop was followed up by a study, which explored the characteristics of learning through interaction with robots. Twenty eight students, from two schools, responded to pre- and post-course questionnaires and had their interactions with robots, videotaped. Our findings indicate that through interactions with animal-like robots, the young students gained understanding of the robotic system and the principles of its programming and operation. We observed numerous expressions of animistic thinking with regard to the robots. Students were closely involved and excited by interactions with the robots. They initiated cooperation with their fellow students to create robot-robot interactions. All the students valued the Workshop highly. While some of the students were especially interested in building robots, the majority was attracted mainly to testing and creating robot behaviors.

4.2 Workshop on "Human and humanoid robot motion" (August 2011)

The workshop connected to the 2011 OlympiYeda theme "Science of motion and sport". The Workshop dealt with this theme from a robotics perspective. Its purpose was to have students learn about the mechanics of human locomotion, through operating a biped humanoid robot to simulate body motions. Sensor-motor behaviors were demonstrated, using the humanoid Nao robot, created by Aldebaran Robotics.

The Workshop comprised three stages:

1. The movement and sensing capabilities of the Nao robot were introduced through analogies with features of the human body, such as robotic cameras and human eyes, gyro and accelerometer vs. human vestibular system, robot engines and gears vs. human muscles, robot microphones and human ears. The ways in which a robot (very much like a human) uses sensor data to move and interact with its environment were demonstrated;
2. During a hands-on session, students practiced programming the Nao robot to perform simple movements and interactions. They learned to use the robot's visual programming environment; and discussed new concepts, such as motor stiffness, parallel programming and error handling. Each student wrote a simple program that makes the robot stand up and wave "hello" with its hand, while greeting the student by name, and then sitting down;
3. In this stage, students designed and programmed robot movements to mimic human gestures, typical of a given sports field (Figure 6). The challenge was to determine the movements according to mechanical limits and robot stability. This required analysis of the center of gravity and the forces acting on the robot in different positions. For example, in order to mimic kicking a football, students

had to first get the robot to lean over one leg and then to perform the kick with the other leg, without falling down.

Figure 6. Design and programming of Nao movements

Student evaluation of educational outcomes was conducted through a post-course questionnaire and videotapes of hands-on activities. As indicated, all the students noted that the Workshop contributed to their knowledge of motion science. Some participants pointed out that the most instructive activities were demonstrations and lectures; while others, preferred the hands-on activities. As indicated by the student observations, the most motivating activity was creating new humanoid robot movements. Students used their own bodies for designing realistic movements and for initial testing of the robot's stability.

5. Conclusions

An important mission of modern science museums is to expose visitors to powerful technological innovations, and to offer educational activities in technology-enhanced environments. Technological systems can be effectively presented, only if opportunities for their active interaction with visitors are provided. This requires development and deployment of robotics technology, providing capabilities of communication and physical interaction. The MadaTech experience, resulting from demonstrations of robotic exhibits, public robot performances, and educational robotics programs, can be summarized as follows.

Contribution of robotics exhibitions and programs:

- A science museum can make a significant contribution to public understanding of modern technology, particularly robotics, a field which opens up opportunities for new and innovative museum activities;
- Robotics demonstrations and programs evoke strong interest among broad and varied audiences;
- Robotics activities motivate boys and girls, of all ages and cultural backgrounds, to come and study at the museum;
- Modern intelligent robots, such as the Nao, Thespian, and Aibo, have proved their effectiveness as performance and program protagonists. The success of robot theatre performances and shows at MadaTech enables us to recommend them to other museums.

Teaching/learning methods that have been effective in the MadaTech robotics programs:

- Self-regulated learning and learning through interaction with the robot substantially enriched conventional robotics instruction based on construction and programming activities.
- Extensive use of analogies between biological and robotic systems contributed to understanding science and robotics concepts.
- Technion students majoring in technology and science education formed the backbone of the MadaTech mentoring staff in robotics programs.

- A combination of competitive with developmental activities has been shown to be suitable for fostering both creativity and learning excellence.

6. Acknowledgement

Educational robotics programs at MadaTech are heavily supported by the Haifa Municipality. Activities at the Gelfand Center for Modeling, Robotics and Communication are sponsored by Mark Gelfand, 2011 Honorary Doctor of the Technion. The authors appreciate the contributions of Dan Cuperman and other students of the Technion Department of Education in Technology and Science.

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