

Preface

The robotics revolution is in its nascent stage, set to burst over in the early part of the twenty-first century. Mankind's centuries-long quest to build artificial creatures is bearing fruit. (Brooks, 2002)

INTRODUCTION

This book of chapters representing a variety of researchers' perceptions examines the topic of educational robotic platforms that are specifically designed for learning. Moreover, the editors approached the subject with an eye towards research and evaluation asking the poignant question – what is the impact, in terms of learning, attitudes, and workforce development, of educational robot platforms in three diverse learning environments: formal classroom learning, out-of-school time, and robot competitions.

Because the field of educational robotics is relatively new, existing literature in this area frequently deals with self-reported learning and enthusiasm towards science, technology, engineering, and mathematics (STEM) subject matters as a direct result of using the educational robot as a tool for learning. This book provides additional evidence for the impact of educational robotics on learning and attitudes and provides evaluation models and examples intended to move the field forward. The editors purposely requested that chapter authors provide detailed research and evaluation designs and measurements, often asking for implementation strategies, protocol, and to report statistical tests when appropriate.

The editors come from diverse backgrounds including engineering, research and evaluation, STEM education, and youth development, and have implemented several large-scale educational robotics programs funded by the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and other private and public partners. As both practitioners and researchers, the editors felt that there was a significant deficiency in the literature linking robotics education with STEM learning and its general impact. Thus, the impetus of this book was to identify leaders in the field of educational robotics and share their findings and best practices in one volume. The compilation provides many exciting examples and variations of using robotics as a tool for STEM education and offers evidence of its effectiveness in a number of different learning environments reaching a diverse audience of learners.

The current interest and popularity of robotics, specifically the educational robotics platforms, arises from a number of different explanations. There is, of course, the power of robotics to excite children and youth. Anyone who has observed youth working with educational robots knows their excitement in building their own robot creation and having it respond to their programming commands. Robots also have tremendous potential to support learning by actively involving students in experiences that tap science, technology, engineering, and mathematical concepts and skills. Another reason for the popularity

of robotics is the relative affordability and decrease in size of the technology. Of course, there are claims that the price is still a barrier for many youth to participate in educational robotics, which in part, is true when looking at affordability to individual families. However, and this brings up the second reason for the perceived popularity of education robotics, the amount of funding available for youth programs centered on robotics is quite substantial and growing. In the United States, for instance, NSF has invested millions of dollars to bring educational robotics to formal and in-formal learning environments through the Innovative Technology Experiences for Students and Teachers (ITEST) and the Discovery Research (K-12) programs. NASA also has developed on-line robotics activities and funded educational projects through the Summer of Innovation (SOI) grants. In addition, many businesses and private foundations have provided generous support to bring robotics to children. For example, Time Warner Cable Inc., one of the largest U.S. video and high-speed data and phone service providers, has distributed significant resources through their *Connect a Million Minds* campaign to promote STEM education through robotics competitions. The widespread availability of educational robotics competitions and the number of volunteers associated with these competitions is another reason for the increase in popularity of robotics in education. Finally, many organizations are producing resources for students and adult facilitators that are built around educational robotics. For example, in 2010 the Boys Scouts of America released the robotics merit badge and curriculum book, and the National 4-H Council released a 4-H robotics curriculum. Combined, these two programs reach more than 8 million children across the nation.

Why Robotics?

Robotics in K-12 Education: A New Technology for Learning is a book about the effectiveness of educational robotics platforms when used as a tool for learning. The modern field of robots has been around for over 30 years. Attempts to develop autonomous mechanisms occurred centuries earlier. However, most recently we have seen an influx of new robotic systems in a variety of areas from space explorations to agriculture, from households to manufacturing production and medical institutions, and certainly through education.

For example, when the second Iraq war started in 2003, there were no ground-based robotic systems in the US inventory. By 2006 there were 5,000 units in the war, and by the end of 2008, there were an estimated 12,000 mobile robotics systems on the ground. According to the International Federation of Robotics, in 2009, the market for service robots worldwide was about 13.2 billion dollars (US). In 2009, 6.7 million domestic robots like vacuum cleaners and lawnmowers were sold and it is projected that an additional 11.4 million will be sold by 2013. In addition, leisure robotics, including educational robotics kits accounted for 3.7 million units sold, and it is projected that another 4.7 million more will be sold by the end of 2013 (<http://www.ifr.org/service-robots/statistics/>).

Defining Robots

Robots are the combination of many different technologies and components acting as one system. In his book “Wired for War: The Robotics Revolution and Conflict in the 21st Century” P.W. Singer (2009) defines them as:

Robots are machines that are built upon what research call the “sense-think-act” paradigm. That is they are man-made devices with three key components: “sensors” that monitor the environment and

detect changes in it, “processors” or artificial intelligence” that decides how to respond, and “effectors” that act upon the environment in a manner that reflects decisions, creating some sort of change in the world around a robot. When these three parts act together, a robot gains the functionality of an artificial organism.

Using the working definition of robots from Singer (2009), many electronic toys with the “robot” moniker are missing one or more key components of a robot, according to the above definition. While these technology-based toys may also be learning artifacts, we as editors, are mainly concerned with robotic kits that can sense, plan, and act. From a learning or educational point of view, a robot brings together many different technologies to fit the “sense-think-act” paradigm. Electronics, engineering, and computer science are large components of robotics and must be explored in order for the robot to work as a system. Of course, other skills like teamwork, critical thinking, problem solving, and engineering design are also needed when creating such a robot.

A Brief History

Looking at the recent past, the word robot probably originated from the Slavic word robota and was first used in the 1921 play R.U.R (Rossum’s Universal Robots) written by Karl Capek. The precursors to the robot, which are self-operating machines or automata, date back 3,500 years to ancient water clocks (Brooks, 2002). The origin of modern self-operating machines can be attributed to Jacques de Vaucanson, the French inventor that created the “canard mécanique” (mechanical duck) also known as “the Defecating Duck” in the mid eighteenth century (Singer, 2009). Vaucanson’s duck and other mechanical humanoid inventions sparked the development a generation of similar automata.

While these early mechanical inventions obviously lacked the key ingredients of the sense-think-act paradigm, they represent the desire and development of machine-based artificial organisms. According to Brooks (2002), William Gray Walter probably developed the first robot capable of the sense-think-act paradigm in 1948. Walter developed small robots he called tortoises that had the ability to react to light. The components of the tortoises contain electric motors, a bump sensor, and most importantly two vacuum tubes used as switching elements that gave the robot the ability to respond to the light sensor data.

In the 1960’s, industrial robots arms like the UNIMATE developed by George Devol, Jr. began to appear in factories like the General Motors plant in New Jersey (Nocks, 2007). The UNIMATE was one of the first industrial robots that could be taught or programmed using metal cylinders and made use of transistors instead of vacuum tubes. The industrial robots of the 1960s were stationary but were revolutionary in the way they combined sensors and stored memory to make such products faster and more reliable.

Through the mid 1960’s and on into the 70’s and 80’s, researchers in the field were moving robots out of factories and making them mobile. In conjunction with this, a lot of work was focused on artificial intelligence (AI). Robots like Shakey, out of Stanford Research Institute Artificial Intelligence Lab (SAIL), and the Stanford CART relied heavily on computer programming to compare sensor data with the robots internal world model in order to achieve mobility. In the mid 1980’s, researchers, including Rodney Brooks, the founder of iRobot, began investigating behavior-based robotics (BBR) that relied less on a preprogrammed computational computer model and more directly on sensors that could directly relay information to the motors or actuators. The BBR model provides us with the modern definition of a robot using the sense-think-act paradigm introduced by Signer.

In the late 1960's, Seymour Papert, at the MIT Artificial Intelligence Laboratory, began investigating the possibility of using a robot turtle tethered to a computer to teach children programming. The work at MIT led to the development of small programmable “bricks” that contained a processor and inputs for sensors and outputs to run motors. Moreover, Papert and the MIT lab created the Logo programming language and worked with the LEGO Company to integrate the programmable brick into the LEGO building blocks. In 1998, LEGO released their RCX Mindstorm robotic kit and RCX programming code for use in education. While the LEGO kit has been commercially successful, it was not the first educational robot.

According Miller, Nourbakhsh, and Siegwart (2008), the *Hero-I* robot developed by Heathkit Educational Systems was the first educational robot and was sold as a kit in the early 1980s. Today there are many other robotic kits available, and the types and variety of such kits are expanding rapidly (Miller, Nourbakhsh, & Siegwart, 2008).

In conjunction with the educational robotics, new ideas for instruction emerged with the idea of constructionism. Kafai (2006) succinctly defines constructionism as the idea of building one's own knowledge, “in interactions with others, while creating artifacts of social relevance” (p.35). Furthermore, robots used in education utilize a problem-centered approach to learning that places a real-world or quasi-real world problem at the center of the learning experience. Placing the problem at the center of the learning experience emphasizes the student constructing deeper knowledge rather than mastery of discrete pieces of information (Druin, 2000).

Competitions

The future of robots depends on continual innovation, and that is why the initiatives to attract grammar and high-school students to the computing and engineering science through funded robot competitions are vital. We need not all be engineer, however, to understand that as with any technology, robots will have the most value where people can grasp their advantages as tools and not as toys.

- Lisa Nocks (2007 p.164.)

Another important development in the evolution of educational robotics was the establishment and implementation of education robotic competitions. Autonomous robot competitions began around the late 1980s in the Electrical Engineering and Computer Science Department at MIT (Miller, Nourbakhsh, & Siegwart (2008). In 1992, the non-profit organization FIRST (For Inspiration and Recognition of Science and Technology) held their inaugural robotics competition for high-school students and in 1998 hosted the inaugural FIRST LEGO League (FLL) tournament (FIRST, 2008). Other competitions like BEST (Boosting Engineering, Science, and Technology), Botball, RoboCup, and many others provide competitive and entertaining environments around robots. The number of participants for most of these educational robotics competitions has experienced exceptional growth. For example, more than 294,000 students are projected to participate in the 2011 FIRST series of robot competitions (FIRST, 2008).

Currently, education robotics has propagated through many educational institutions and informal learning programs providing an effective integration of science, technology, engineering, and mathematics concepts and an entertaining and challenging leisure experience. Education robots also have the ability to reach an expanding diversity of learners through their engagement with robotics-based educational experiences during their K-12 school years. Such experiences also may impact youth career planning

and other important life decisions. The relationship between robotics education and learners' experience can be found in this book, from the perspective of a variety of authors, representing many different educational backgrounds and contexts. Enjoy the reading, and share their insights into the power and potential of educational robotics in today's formal and informal learning environments.

The Scope and Limitation of this Book

As this book examines the use of educational robotics in three distinct learning environments including formal classroom learning, informal and non-formal environments, and through educational robotics competitions, several different robotics platforms are discussed and presented with diverse education goals and learning objectives. Some chapters discuss specific programs implemented to satisfy unique needs or challenges in a certain geographic area. Other chapters discuss broad regional and national programs and competitions with large numbers of youth participants. While the objective of the book was to provide specific evidence of the effectiveness of educational robotics in the learning of STEM content and general impact to increase human potential, it is important to realize that the results may not be transferable to all robotics programs. More research is needed to identify what aspects of educational robotics work with what types of audiences and under what conditions. There is also the need for additional types of measurements and research protocols to answer the basic question of effectiveness.

How to use this Book

Seventeen chapters (across four sections) are arranged in logical order from theoretical and instructional perspectives, educational robotics in formal learning environments, programs conducted in in-formal learning environments, and robotics competitions. In the chapters discussing particular educational robotics programs, research-based measurements of the project's impact are reported. In addition, detailed program implementation information from a variety of learning contexts is shared. A recommended strategy for reading this book is to start with the first section on theory and then move into the specific learning environment (formal, informal, or competitions) that may well capture the reader's interest.

In section one, "Theoretical and Instructional Perspectives," the first chapter, "Theories Behind Educational Robotics," provides a theory-based approach to implementation of an educational robotics program. The second chapter, "Designing Evaluations for K-12 Robotics Education Programs," provides an overview of evaluation strategies to use with educational robotics programs and provides guidelines for their use. The third chapter, entitled "Generating Transferable Skills in STEM Through Educational Robotics Programs," highlights the need to implicitly target STEM skills that prepare students to further pursue academics and careers in STEM related areas. Finally, the fourth chapter, "In and Out of the School Activities Implementing IBSE and Constructionist Learning Methodologies By Robotics," explores the inquiry based science education (IBSE) framework and provides specific examples of the IBSE being applied in European classrooms.

In section two, "Educational Robotics in K-12 Formal Learning Environments," chapter five, "Robotics and Problem-Based Learning in STEM Formal Educational Environments," discusses problem-based learning and the development of the NSF-funded CEENBoT educational robotics kit used in middle-school classrooms. This chapter also discusses a new instructional design method for delivering robotics lessons. The sixth chapter, "Medical Robotics in K-12 Education," explores the use of educational robotics with an emphasis in biomedical engineering topics for students in grades 7-12. This chapter also

examines teacher professional development topics including how to develop and implement standards based lesson plans in surgical robotics. The seventh chapter, entitled “Robots Underwater! Learning Science, Engineering & 21st Century Skills: The Evolution of Curriculum, Professional Development and Research in Formal and Informal Contexts,” presents the *WaterBotics*TM, an underwater robotics program that uses the underwater environment, where issues such as buoyancy, stability, drag, thrust, and drift are used to create unique and challenging problem-centered learning environments. The final chapter in section two, “Programming Robots in Kindergarten to Express Identity: An Ethnographic Analysis,” examines the use of robots and a specialized programming tool for very young children. The chapter focuses on teaching ideas and concepts from computer science in a Kindergarten classroom.

In section three, “Educational Robotics in Out-of-School Time,” the ninth chapter, “The Impact of Educational Robotics on Student STEM Learning, Attitudes, and Workplace Skills,” discusses the impact of a summer camp robotics-based program. The chapter presents the methods of collecting and analyzing cognitive and attitudinal data in a challenging non-formal learning environment. Chapter ten, “The Mediating Role of Context in an Urban After-School Robotics Program: Using Activity Systems to Analyze and Design Robust STEM Learning Environments,” describes the cultural-historical activity theory (CHAT) as it applies to an after-school robotics program. The chapter also provides an activity systems framework for afterschool educators to design successful programs. The eleventh chapter, “Building Technical Knowledge and Engagement in Robotics: An Examination of Two Out-of-School Programs,” describes and analyzes two educational robotics based afterschool programs, the Digital Youth Network (DYN) and the Robot Diaries (RD). The chapter concludes with design considerations for afterschool educators.

Chapter 12, entitled “STEM Outreach with the Boe-Bot,” discusses the rationale for choosing the Boe-Bot for an Introduction to Systems Engineering program for middle school youth in an afterschool program, along with the pre-to-post test results on learning and attitudes. Chapter 13, “Developing and Evaluating a Web-Based, Multi-Platform Curriculum for After-School Robotics,” describes the development of the on-line Internet Community of Design Engineers (iCODE) project that uses two unique microcontrollers, the Super Cricket and the Breadboard Microcontroller Starter Kit. This chapter also discusses established mastery levels for participants and program evaluation protocol and results. Finally, the 14th chapter entitled, “Learning Geospatial Concepts as Part of a Non-Formal Educational Robotics Experience,” further expands the project presented in chapter 9, focusing on the integration of geospatial technologies with mobile robotics.

In the fourth and final section, “Learning through Educational Robotics Competitions,” chapter 15 explores the metaphor of the STEM pipeline for developing human potential in STEM areas and provides evidence that robotic competitions may support youth entering and traversing the pipeline. Chapter 16, entitled “Promoting Diversity and Public School Success in Robotics Competitions,” explores the demographic makeup of youth participants in educational robotics competitions and argues that efforts such as a power rating for teams can enhance underrepresented students experience and learning. Chapter 17, “Educational Robotics as a Tool to Broaden Participation in STEM for Underrepresented Student Groups,” discusses the lack of underrepresentation of women, minorities, and students with disabilities in STEM career areas and proposes options, strategies, and resources to provide equal access for all youth.

The editors sincerely hope that this collection of carefully researched, diversified and widely spread experiences with educational robotics will contribute to the scientific knowledge base of the learning and attitudinal impacts of educational robotics. In addition, they hope that the book will further inform the public perception of the relevant benefits of such new learning tools for the new generation. It is

important for every family, community, nation, and the world that the next generations attain an appreciation of the power of knowledge and new tools for education to lead to a more sustainable and prosperous future around the world.

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