Using robots to teach non-engineers about science and technology

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Abstract

One of the challenges in the future of engineering education will be to teach the power and limitations of science and technology to people who are not intimately involved with the fields of science and engineering. As technology becomes more powerful, it becomes even more crucial for everyone from legislators to businesspeople to elementary school teachers to understand how science works, and how engineers leverage science and employ heuristics to design useful things. It is also important that people understand the limitations of science and what kinds of problems cannot be solved by more manpower, money and technology.

This paper describes the proposed use of small programmable semi-autonomous robots in a modeling course for non-majors. By observing the behavior of these robots, students form hypotheses about the contents of the controller. Experiments can be set up to determine if the hypothesis is correct, and incomplete or incorrect hypotheses are be revised and retested. In this way, the scientific method and Occam's razor can be investigated in an environment with fewer off-topic distractions than the traditional introductory physics or chemistry laboratory. Once a predictive model is achieved, design can be approached by beginning with a desired model and iteratively constructing prototypes that approximate and finally achieve the specified behavior. The strengths, weaknesses and societal impact of robotics and automation in specific, and technology in general, can be approached from this base.

If non-engineers understand how science and technology work, they can better interact with scientists and engineers in the workforce and make informed decisions about when technology can be a solution to a problem, and when other solutions are better. Additionally, it is important that non-engineers understand enough about science and engineering that they can apply this technology where it is most useful to society.

I. Introduction

Technology and science play an increasingly important role in society. Today, it is more crucial than ever for nonscientists to understand the basic workings of science[4], and how engineers leverage this science and employ heuristics to design useful things.

One traditional manner in which some liberal arts and sciences institutions have addressed scientific and technological literacy is to require an introductory physics or chemistry course, in which one learns how science works by performing science. In these courses, students are exposed to the modeling and analysis of physical and chemical systems, and perform several experiments to gain understanding of these systems. For many nonscientists, this is the only educational exposure that they receive in the sciences.

Science education in these courses is often *implicit*, in that the structure and methods associated with science as a whole are not discussed, but the relevant implementations of these general methods are learned in the appropriate context. These courses also rarely address design, which can be thought of as the converse of science. In one approach to design, a model of a system that has been developed through the scientific *analysis* of behavior is used to *synthesize* a system that exhibits a specified behavior.

For these reasons, we believe that there is a need for courses to educate nonscientists about science in general, and engineering in particular. These courses, which we shall call “nonmajors courses” are not to be confused with introductory courses in engineering that are intended to orient students in the field and prepare them for further study. Nonmajor courses may be terminal courses and should provide a broad exposure to science and include study and discussion on the impact of science and engineering on society, as well as provide a view as to the thought processes and methods used in the pursuit of science and engineering.

Nonmajor courses share many characteristics with previously developed courses, such as those described by Gurwitz[2] and Denenberg[1] that are intended to teach an overview of computer science to nonmajors. These courses focus on teaching the methods of science and engineering without teaching a particular in-depth implementation of those methods.

II. Barriers to nonscientists (and nonengineers)

There are many barriers to the nonscientist who wishes to understand just what science and engineering are and how scientists and engineers go about what they do. The amount of prerequisite knowledge and skills involved in order to understand most scientific material is considerable. Most course material and curricula seem oriented to the student who wishes to become involved in the practice of science and engineering, not for those who need insight into the philosophy and methodology of science and engineering.

Nair and Majetich[3] identify three distinct motivations for students taking introductory science and engineering courses: (1) for science literacy, often as a distribution requirement, (2) for required background knowledge in other fields, and (3) for interest in the subject matter itself. Nair and Majetich note that these courses have a common problem of teaching to the third group, which is often the smallest one. Students in the first two groups may not achieve their personal goals in taking the course. By focusing explicitly on the first group, we intend to reduce the motivational barriers commonly involved with the use of introductory science courses to teach science literacy.

III. Robots as “natural systems” for scientific inquiry

We intend to utilize small, wheeled, semi-autonomous robots as “natural systems” for students to analyze and model. In addition to the motivational aspects involved with these robots, they are excellent systems to model due to their known capabilities, simple and structured control, and deterministic behavior.

The Lego “MINDSTORMS Robotics Invention System” consists of a self-contained battery-operated microcomputer (the RTX) and a selection of building blocks such as wheels and supports that attach to the RTX to construct a robot. Touch (bumper), light sensing, and motor blocks are also included. These attach to the RTX or supporting blocks, and exchange signals through wires with the RTX. A flowchart-based graphical program is developed on a Windows personal computer and is downloaded to the RTX through an infrared transmitter that is supplied with the kit. The RTX can then follow this program, reacting to the sensor inputs as desired. This system allows students to program a semi-autonomous robot in a relatively straightforward manner from a standard computer, without learning difficult and arcane programming languages.

With a reasonable introduction to the facilities and control structure associated with the robot, the scientific method can be introduced to the students in the context of discovering the controller that has been implemented inside a robot.

1. Observation:
   The behavior of the robot is observed in several situations. The response of the robot to the activation of its sensors is observed.
2. Hypothesis:
   A software controller is hypothesized for the robot. This should be the simplest controller that exhibits the observed behavior of the robot (Occam's Razor). Example: if the robot has been observed moving for two seconds and stopping at a black line, it could be hypothesized that the robot stops at all black lines. From this behavior, there would be no reason to predict, for example, that the robot stops at all black lines it sees after one second.
3. Experiment:
   The robot is tested to determine if the behavior of the controller matches the observed behavior of the robot. Each portion of the hypothesized controller is tested.
4. Theory:
   If the observed behavior matches, the hypothesis is *not* disproven, and is treated as a working theory. If the observed behavior does not match the hypothesis in a given area, the hypothesis is disproven. In our example, a black line could be placed at different intervals from the robot, to see what the robot does. If the hypothesis is correct, the robot will stop at all black lines as it reaches them.
5. Proof:
   As in the natural world, absolute proof is not available. There can always be situations in which our testing did not reveal differences between the theory and the system. For example, the robot could actually be programmed to stop if a black line is observed at *exactly* one-half

second and two seconds from the beginning of the program. Since this condition is not likely to be triggered in the testing, this difference could easily go unnoticed.

6. Hypothesis Revision:
   If the robot does not behave as expected in a given situation, the hypothesized controller needs to be changed to account for the observed behavior. To continue our example, if the robot ignored all black lines it encountered before one second, the hypothesized controller would need to be revised to include this proviso.

It is our belief that this method will eliminate some off-topic discussion when teaching science. By utilizing a flexible system whose behavior is known, very little ancillary material needs to be taught. This allows us to concentrate on the methods and structure of science without placing undue emphasis on the often-difficult manipulations and testing involved with many actual *uses* of science, such as chemical or physical systems.

The experiments, of course, are not the only component of the course. Readings from the history of science and from materials that provide descriptions of alternative views of scientific processes “wrap around” the experiments.

IV. Robots as “manufactured” systems requiring design

A knowledge and appreciation of how scientists analyze and model systems is important to the well-educated student of today. Equally important to this student is knowledge and appreciation of how engineers utilize these models and employ judgment and heuristics to design systems that perform specified tasks.

Once again, the flexible system available to us in the small wheeled robot allows the elimination of off-topic mathematically based analyses in favor of direct discussion of the design of systems. The system is sufficiently complex to illuminate the steps of the design cycle, but simple enough that students are not distracted by difficult analysis and modeling tasks.

A design example would be a controller to follow a black line on the floor. The steps in the design are as follows.

1. Problem Identification/Goal definition:
   The problem statement is reduced to a meaningful one: the robot must not veer off the black line as it moves forward.
2. Data Gathering/Generate Ideas:
   On the basis of previous analyses, an idea might be to use light sensors to determine when the robot is veering off the black line. This information could be used to correct the situation.
3. Analysis of potential solutions/develop models:
   Several possible controllers with the appropriate sensor inputs could be analyzed. If none of these controllers seems to solve the problem, more data and ideas are needed (Step 2).
4. Make a decision/Communicate and specify:

A design in the form of a possible controller can be implemented via relatively user-friendly software (see Section III). Explicit programming is not used, due to the overhead involved in learning a procedural language and the "technophobic factor."

5. Review and assessment of design:
   After the controller is downloaded into a robot, the solution is tested to see if it performs according the analysis in Step 3 and meets the specifications in Step 1. If it does not, Steps 2-5 are repeated.

The given exercise is intended as an example. As we plan to do for the "scientific" component of the course, we will utilize a selection of materials describing the design process to provide an overview of what engineers do and how they might go about design.

V. Discussion

We have illustrated one way in which small semi-autonomous wheeled or tracked robots can be used as a common tool in a science and engineering course for nonmajors. While being reasonably flexible, the system is simple enough to allow students to focus on learning the fundamental properties and methodologies of doing science and doing design without becoming mired in the depth required for introductory courses for the major.

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