Building and Assessing a Hands-on Learning Experience for Robots in Business and Society

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Abstract

An undergraduate course is being developed for non-engineering majors to address the need for general competencies in ethics, science, and technology. Robotics is a field of science that is rapidly transforming our lives. Participants in the course will learn the history, mechanics and software, and applications of robots and learn to analyze the ethical, social, and economic concerns. The unique feature of the proposed course is that the participants will use hands-on assignments with a LEGO Mindstorm kit (interlocking plastic bricks, gears, computer) to explore these issues. For example, students will use the LEGOs to build a face for a robot that expresses emotions as an exercise to more deeply consider the use of robots as surrogates for human interaction. The course will be monitored and updated using formative and summative assessments including a modified "Views on Science-Technology-Society" (VOSTS) tool. Trial use of the VOSTS tool is described.

Keywords

STS, VOSTS, technology

Background

Either directly or by proxy we make daily decisions that affect the course of science and technology development and hence our lives. As we act as consumers, voters, and religious, business and political leaders we are choosing between technologies, rejecting certain technologies, or approving other technologies. When we purchase a product we may understand the local implications of the good or service, e.g., it is cheaper, but we do not necessarily think about the larger implications such as environmental impacts or strategic effects on the country, e.g., the flood of counterfeit electronic components supported by consumer electronics purchases that is affecting military procurement. We pay even less attention to more distant decisions; as citizens we are not asked to make direct decisions about military strategies, such as use of depleted uranium bullets. Unfortunately, whether or not we seek the information to make complete choices and demand to have our choice recognized, the decisions will happen by default. Thus it is imperative that members of a highly functioning, sustainable society be motivated to seek to understand the source and implications of new technologies and collectively make "good" decisions about adoption of those technologies.

This need for science and technology savvy citizens has been recognized by most universities and integrated into undergraduate curriculums. Whether this curriculum thread is named "Science, Technology, and Society", "Culture, Science and Technology", or "Science and Technology in Society" (STS - the designation used at Clemson University and that we will use throughout this proposal), it refers to the attempt to motivate students to be inquisitive about the broader implications of science and technology and give them tools to analyze the potential pros and cons of emerging ideas. The need for such learning is widely recognized; however, the approach to teach the tools and the means to evaluate the level of competency is still evolving. In spite of such disagreements over pedagogy, it appears that there are some core skills and values that any form of the training should instill[1]. To contribute to the discussion of a scientific or technological issue, citizens need not only skills in evaluating technical concepts but also tools to evaluate the larger social issues involved in any debate.

Robotics is a field of technology that is rapidly transforming our lives. For example, remotely controlled military aircraft have already transformed the country's approach to foreign policy and we are on the verge of deploying robots that make life and death decisions on the battlefield without human intervention[2,3]. As the government represents us and we are ultimately responsible for the policies, are we willing to delegate such decisions to automated equipment? The issues raised by use of artificial intelligence and artificial conscience may be complex and nonobvious, for example, it has been proposed that robots could potentially make more ethical decisions than humans[3]. An educated population and leadership must decide on this use of technology or it will happen by default. As a second example, robots have been proposed and are being heavily funded as the solution to taking care of the aging population; that is, robots must account for the shortfall in human caretakers. Is this how part of our population should be treated? An educated population and leadership must decide or it will happen by default. Robotics is a complex field that will greatly affect our society and is thus very amenable to study while learning a general framework to analyze the connections between science, technology and society. Topics can be easily drawn from robotics to help students learn to address the issues created by the complex interactions among science, technology, and society.

It is becoming increasingly difficult to intuitively separate fact versus fiction when it comes to robots. It is even more difficult to understand the pros and cons of robot applications and to make informed decisions. As an example, consider an advertisement for surgical robotics along with the robot that would actually be used in the surgery. Intuitive thinking might suggest that the surgical robot would be better than a conventional surgeon because it could be more precise and hence the higher price of the robotic surgery would be worth the higher cost. The answer has been hotly debated, the fact that surgical robots are often purchased from the hospitals' marketing budgets suggests that the analysis is likely imprecise. One current study does suggest that the results for robot assisted laparoscopy are slightly better than standard laparoscopy and so there is an overall reduced cost to the hospital for robotic surgeries[4]. Robotics applications like this can provide interesting economic case studies.

Course Design

Our ever-present goal is to excite undergraduates to learn more about the STEM disciplines. We hypothesize that the study of robotics will help integrate and reinforce learning from all the student's courses and thus help ensure that we graduate high-quality science and technology savvy students. The course will be offered as a three (3) semester-hour course (45 Classroom Hours) in the Department of Electrical and Computer Engineering, i.e. ECE 101 - Robots in Society and Business, that meets the STS requirement at Clemson. The course will guide the student through the technologies that are used to build robots and the capabilities of robots in current applications. We will answer questions such as "How does the Roomba robot clean the floor in a house?" We will explore the economics of robots and their use as a tool to boost productivity. The lecture topics will be reinforced with hands-on projects -- the students will use LEGO Mindstorms to explore robot construction and intelligence. We will analyze emerging trends to develop our own predictions for the future of robotics. The projects will culminate with a design project where students work with a group to build their own walking robot. In their future careers as business leaders, educators, physicians, etc. students will make decisions about robotics; the course outlined below will provide the tools they need to make good decisions.

1. **Living and Working with Robots (**<u>*7 hrs class)*</u> The course is motivated by the pervasive use of robots (and automation) and the impact on our lives. The use of robots has evolved from "hidden" uses in factories, space and underwater exploration, and laboratories to more direct consumer contact in applications such as surgery (many local hospitals have a Da Vinci surgical robot), housekeeping (the $200 Roomba robot is available at Target stores), lawnmowers (anyone with $3000 can buy the Husqvarna autonomous, solar-powered lawnmower), entertainment (toy robots), companionship (Genibo QD is an autonomous pet robot that displays emotion, mood, intelligence, character, and intimacy through artificial intelligence), transportation (the 2011 Ford Focus is essentially and autonomous robot in the parallel-parking mode), and military (we receive almost nightly updates of drone attacks in Afghanistan with total deaths near 3000 persons). Complicating the practical, ethical and economic analysis of robots, our perception of robots is shaped by their portrayal as either extreme friends or foes in movies and books.
    - Project 1: Introduction to the LEGO Mindstorms NXT 2.0 kit. This project will explain how to connect to a laptop computer to the LEGO Mindstorms NXT 2.0 via USB cable and Bluetooth. Use the LEGOs to build a face for a robot that expresses emotions as an exercise to more deeply consider the use of robots as surrogates for human interaction
2. **Building and Controlling Robots (**<u>*9 hrs class*</u>) All robots can be described as a collection of common components such as electronic sensors, cameras, computers, software, mechanics, and a power source. The organization of these components, the robot design, allow robots to see and feel the world (senses), make decisions (intelligence), and respond (motions and speech). The basic operation and output information from sensors such as accelerometers, gyroscopes, torque, force, color, digital compass, infrared emitter/detector, and sonar will be described. The common actuators used to move a robot, electric motors, muscle wires, and air and hydraulic cylinders, will be examined. The underlying tools of kinematics, dynamics, motion planning, and coordination will be overviewed.
    - <u>*Project*</u> 2: Motors This project is an introduction to the use of the LEGO Mindstorms NXT motors.
    - <u>*Project 3*</u>: Ultrasonic Sensor This project will introduce you to the Mindstorms ultrasonic sensor. The ultrasonic sensor can be used to determine the distance from the robot to an object. Sensor will be used to create a control system to have the robot follow a wall.
3. **Artificial Intelligence** (<u>*8 hrs*</u> class) Computers can perform monotonous calculations efficiently and reliably, jobs humans don't like to perform. However, computers have trouble understanding complex environments and problems, where a human would perform well. Artificial intelligence involves capturing human skills and intelligence, and applying them to the computer to solve these complex problems. The future potential of artificial intelligence is an important debate in considering how robots may affect society.
    - <u>*Project*</u> 4: Touch Sensor This project will introduce students to Mindstorms sensors, using the touch sensor as an example. The touch sensor is the simplest of the sensors included in the Mindstorms kit. It simply returns a value true or false indicating whether

it is being pressed or not. This project will cover how to use the touch sensor in a program.

- *Project* 5: Color & Light Sensors Robot is programmed to drive around in a figure eight pattern with the aid of a sensor.

4. **Economics of Robots (***5 hrs class)* The basis for making good economic decisions regarding robots will be discussed. It seems intuitive that choosing a robot that can perform a task faster, better, and more reliably than a human counterpart is an easy economic choice. However, many hidden and complex benefits and costs confound such decisions. As an example, it has not been clear if robotic surgery is cost effective. A recent study shows that in terms of direct costs, surgery with the daVinci robot costs about $3000 more per operation than having a surgeon perform the same operation. Surprisingly, when the total cost to the hospital is considered, the savings through avoided complications and associated blood transfusions translate into a $700 savings per operation. Traditional hand-harvesting of grapes cost $494 an acre in 2006, compared with $282 an acre in 2008 after automation. In other cases the additional cost of a robot may yield an increase in quality.
5. **Ethical Issues** (*6 hrs class)* One definition of a robot is "a mechanical device for performing a task which might otherwise be done by a human" - deciding whether to replace a human with a robot has direct and far reaching effects. The economics of robots often suggest a business advantage for replacing workers with robots. This choice raises questions about the commitment of a company to employees and the overall effects on society. The other side of this question is situations where robots can replace workers in dangerous or repetitive task but at a higher cost. How does a company choose between higher cost and human health?

   The use of robots as surrogates in military encounters raises many ethical questions. Robots may make decisions devoid of favorable human qualities such as compassion, what are the risks of empowering robots? Who is ultimately held responsible for the actions of a robot? Are robots counterproductive to the larger goal of peace, because lower casualties and lower political risk make engaging in war become the most convenient method of conflict resolution? We will explore the pros and cons to the exponentially-advancing robot technology.
6. **Our Future with Robots** (*8 hrs class)* The future of robotics including nanorobots, humanoid robots, snake-like robots, flexible robots, self-replicating robots, courier robots, autonomous vehicles, self-reconfiguring modular robots, human enhancement technologies, and robot swarms. How will such new technologies change the impact of robots on society?
7. **Design Project** After gaining a firm understanding of' the fundamentals of design and the use of the Mindstorms, the student teams will complete a design challenge by designing, building, and programming their own robot. Final report will include an analysis of the ethical and social impacts of deploying their device.
8. **Assessment** *(2 hrs)* A pre- and post- class *VOSTS test will be administered*

Development and Demonstration of VOSTS Assessment Tool

The original Views on Science-Technology-Society (VOSTS) survey[5] contained 114 multiple-choice questions spanning seven categories and was described by Aikenhead[6]. Mack *et al.* described refinement of the VOSTS tool[7] in which the test was reduced to thirty-one questions in seven sections, this experience suggested that the test could be further simplified, a set of thirteen questions spanning six categories were proposed as shown in Table 2 with general topics indexed in Table 3. Background information was collected using the questions in Table 1. Data was collected using informed consent and protocols approved by Clemson University IRB.

Table 1: Background questions asked of participants..

#	Questions:
H1	I have read the informed consent and certify that I am 18 years old or over and give permission for my survey data to be used for research purposes. o Yes o No
H2	Inside Clemson University, which college are you enrolled in? A. College of Agriculture, Forestry, and Life Sciences B. College of Architecture, Arts, and Humanities C. College of Business and Behavioral Sciences D. College of Engineering and Science E. College of Health, Education, and Human Development
H3	What class are you in? A. Freshman B. Sophomore C. Junior D. Senior E. Other
H4	What is your age? *number*
H5	What is your gender? A. Male B. Female C. I'd rather not say
H6	Which ethnic groups are you in? A. Asian B. African American C. Hispanic D. Native American E. Pacific Islander F. White G. Other
H7	How comfortable are you with new technology, in the scale from 1 to 5 (1 - I generally stick to older technology as long as possible to 5 - I will try any new technology as soon as it is available)? A. 1 B. 2 C. 3 D. 4 E. 5

Table 2: Questions/statement used in the VOSTS-based survey tool. The Code is used to classify questions[6]*, the first digit is the section, the next two digits refer to the topic number, the fourth digit indicates the item number, and the fifth digit indicates similar versions of the same question.*

#	Code	Question/Statement
Q1	10211	Defining what technology is, can cause difficulties because technology does many things in the United States. But MAINLY technology is:
Q2	40531	More technology will improve the standard of living for Americans.
Q3	20141	Politics in the US affects American scientists, because scientists are very much a part of American society (that is, scientists are not isolated from society).
Q4	10411	Science and technology are closely related to each other:
Q5	40412	Science and technology offer a great deal of help in resolving such social problems as poverty,

		crime and unemployment.
Q6	40211	Scientists and engineers should be the ones to decide what types of energy the US will use in the future (for example, nuclear, hydro, solar, or coal burning) because scientists and engineers are the people who know the facts best.
Q7	80211	Technological developments can be controlled by citizens.
Q8	20111	The US government should give scientists research money to explore the curious unknowns of nature and the universe.
Q9	60611	Today in many fields of science in the United States, there are many more male scientists than female scientists. The MAIN reason for this is:
Q10	40311	We always have to make trade-offs (compromises) between the positive and negative effects of science and technology.
Q11	80111	When a new technology is developed (for example, a new computer), it may or may not be put into practice. The decision to use a new technology depends *mainly* on how well it works.
Q12	80131	When a new technology is developed (for example, a new computer), it may or may not be put into practice. The decision to use a new technology depends on whether the advantages to society outweigh the disadvantages to society.
Q13	70212	When scientists disagree on an issue (for example, whether or not low-level radiation is harmful), they disagree mostly because they do not have all the facts. Such scientific opinion has NOTHING to do with moral values (right or wrong conduct) or with personal motives (personal recognition, pleasing employers, or pleasing funding agencies).

Table 3: Section names in the VOSTS question inventory.

Code	
1xxxx	Science and Technology
2xxxx	Influence of Society on Science/Technology
4xxxx	Influence of Science/Technology on Society
6xxxx	Characteristics of Scientists
7xxxx	Social Construction of Scientific Knowledge
8xxxx	Social Construction of Technology

The test was delivered as an unscored BlackBoard™ quiz. The quiz is accessed through individual student logins and the student can only view their own responses. The user was first presented with the informed consent form and queried for acceptance of conditions of participation.

The questions may have up to eleven responses that were assigned into a four point scale. User responses were assigned a score based on a 0-4 scale. A score of “0” suggests no knowledge or appreciation of the topic and “4” suggests a high level of sophistication in considering the topic. A higher score on any question is regarded as more favorable. Some answers represent equivalent levels of sophistication in thinking about a topic but offer different conclusions – these responses were given the same score.

Table 4: Scoring rubric.

Response	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
A	1	1	4	2	4	1	2	2	1	3	2	3	3
B	2	2	4	4	4	1	3	2	1	3	4	4	1
C	3	2	3	3	3	2	4	3	2	4	2	2	2
D	2	3	2	2	3	4	2	4	3	2	3	4	4
E	4	4	1	1	1	3	4	1	2	2	1	0	4
F	3	3	1	0	1	3	2	1	4	2	2	0	3
G	4	0	1	0	0	2	2	0	3	4	3	0	1
H	0	0	0	0	0	0	0	0	2	1	4		0
I	0	0	0		0	0	0	0	0	0	0		0
J	0		0			0	0		0	0	0		0
K									0	0	0		

The survey was administered in two courses offered during the 2014 summer session at Clemson University. Students in ECE6550 - Robot Manipulators were seniors and graduate students in electrical or mechanical engineering taking a technical course on robotics. Twenty students completed the survey at the start of the course. Students in HIST1220 - History, Technology, and Society were sophomore – seniors in a history of technology class, most were engineering students. Eight students completed the VOSTs survey at the start of the course and at the end of the course (pre-test and post-test).

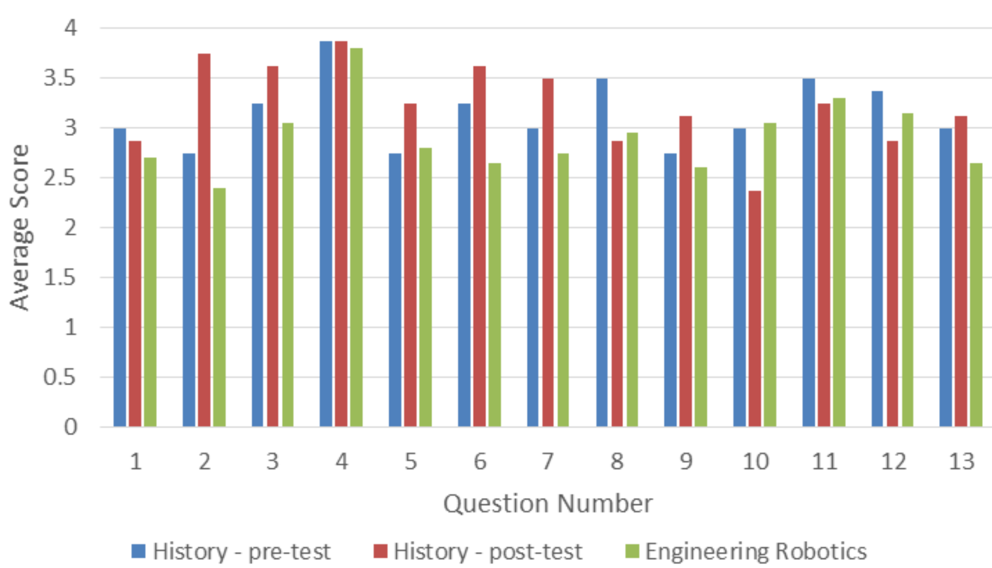

Figure 1: Average of Responses by Question Number.

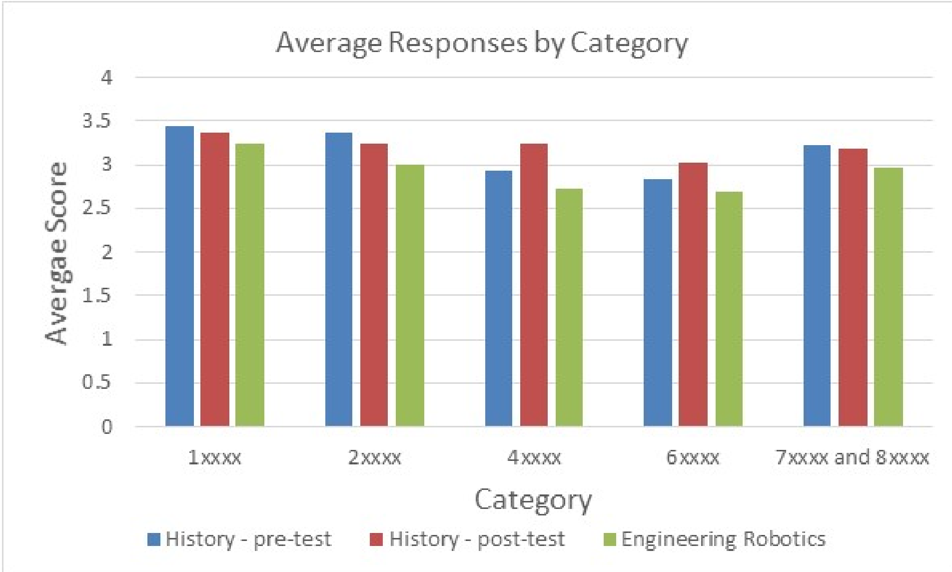

Figure 2: Average of Responses by Category (Section).

Qualitative observations were made towards improving the VOSTS results and identifying major trends within the subject pool. The purpose was not to evaluate either class or make strong interpretations of the scores. There was not sufficient supervision of the assessments nor confidence in the new scoring system to perform statistical analyses. However, several observations and trends provide guidance about the current embodiment of the test and potential improvements.

Q1 and Q4 are designed to discover the respondent's perception of the boundary definitions of the space considered as Science and Technology. One of the more surprising results were the low rated responses to Q1. The highest regarded answers were "F. inventing, designing and testing things (for example, artificial hearts, computers, space vehicles) and "G. ideas and techniques for designing and manufacturing things, for organizing workers, business people and consumers, for the progress of society." which coupled the idea of a device or system with the novelty of the idea and the possible impact and risk of the idea. Respondents in both the history class and the engineering class seemed to focus on the physical manifestation of the device rather than the effects. This was not changed in the history course after completing the course. All respondents did respond favorably on Q4 "B. They are closely related to each other: because scientific research leads to practical applications in technology, and technological developments increase the ability to do scientific research."

Q9 is written to examine attitudes on the role of women in science and technology. The responses from the engineering course students were rated slightly lower than the pre-assessment responses from the history course. And there was an apparent increase in the rating of the responses from the history class in the post-test relative to the pre-test. In general, the responses from all groups were rated about three on the four point scale. One specific response chosen by many respondents "H. There are NO reasons for having more male scientists than female scientists. Both sexes are equally capable of being good scientists, and today the opportunities are equal." was rated as a three on the evaluation score because it acknowledged the potential of women and the opportunities available in education and work but failed to recognize history and the need to be aware of other barriers to full participation in science and technology by all groups. An alternate perspective to this question is that the students have grown up in an environment where they do see equal opportunities for men and women and that something significant has been achieved in society in general. The sensitivity of the scores to a question with potentially multiple implications will direct us to recalibrate the scoring rubric. These responses point to a real question about the attitudes of those participating in a science and technology career compared to those looking at such a career from the outside – this is a topic we will consider further. Additional background questions may help categorize cultural bias in this question.

The questions related to "Influence of Science/Technology on Society" suggest some improvement in the history class participants. The history class average was slightly higher than engineering class at the pre-test, suggesting a more positive appreciation of this topic by the history class participants than the engineering class students. An important part of engineering training is the ABET criteria "h. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context". Accredited programs train students and evaluate them on this topic, it was expected that they would have a higher score in this category.

The "Social Construction of Scientific Knowledge" and "Social Construction of Technology", which comprise the most questions, showed only slight improvement from the pre-test to the post-test. We will need to resolve between possible explanations going forward: i) the course did not train to this dimension, ii) the questions did not effectively measure this dimension; iii) the students were overconfident in their pre-test answers and a more informed opinion was reflected as the same score. Since this was not an assessment of the history class, we will watch for this in the actual robotics class and adjust the assessment or course content as needed. Again, there is the discrepancy that the engineering students scored lower on average than the history students.

Summary

We believe the proposed course has a high likelihood of success since it relies heavily on learning about robotics, a field of technology that is clearly transforming our lives. Existing components with proven success, including the LEGO equipment and exercises used in freshmen engineering courses have been proposed for the hands-on component. Further, since most of the outputs of the project will be captured in the curriculum and structure of the undergraduate course, the impact will be sustainable and long lasting.

With minor modifications, the VOSTS assessment should serve the intended purpose of measuring progress on Science and Technology thinking during the robotics course.

Acknowledgements

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Dr. Burg has extensive experience in industrial applications of robotics and nonlinear control design techniques and the academic investigation of the basis and future directions of these techniques. He moved to Kansas State from Clemson University in 2014. Prior to that, he worked for Michelin Americas developing systems to predict tire performance and at Huffman Corporation designing control systems for machine tools. Current projects include haptic trainers for laparoscopic training, force control algorithms for robots, and control of unmanned aerial vehicles. Dr. Burg strives to connect research at the university level with K-12 students, for example, he is very involved with the Women in Science and Engineering program.

Pamela Mack, History Department, Clemson University

Professor Mack is a specialist in the history of technology and science. She has coordinated the Science and Technology in Society (STS) program at Clemson University since its inception in 2005. Prof. Mack organizes a series of workshops to help faculty in a wide range of departments develop courses that would meet STS requirements. She has also investigated how to assess the effectiveness of courses meeting the STS requirement. Prof. Mack does research on history of technology, including women in engineering, and environmental history.

Richard Groff, Electrical and Computer Engineering Department, Clemson University

Dr. Groff specializes in applications of controls and robotics. His current projects include control of bioreactors to optimize production of biopharmaceuticals; fabrication, testing, and control of novel flexible magnetic and electrostatic actuators; and the study of mechanical intuition for machines.

Ian Walker, Electrical and Computer Engineering Department, Clemson University

Professor Walker's expertise centers on robotics. His current projects include biologically inspired "tongue, trunk, and tentacle" continuous backbone robotics, and robot environments for promoting literacy in children.