Teaching Robotics Through Self-Directed Learning (Or Is It The Other Way Around?)

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Self-directed learning is a meaningful and effective vehicle to expose students to a wide range of topics in an introductory robotics course. Yet the reverse is also true: the diversity and the popularity of robotics are very effective vehicles to train students in the skill of self-directed learning and to promote the notion that a competent professional in our modern society must be skilled as a life-long learner. This paper describes the encouraging results from teaching an introductory robotics course at the baccalaureate level that utilizes self-directed learning as a method to supplement the traditional content of the course. Through this method, students are exposed to specialized areas of interest in robotics such as artificial intelligence, machine learning, evolutionary robotics, and biomimetics. In addition, the activities practice soft skills that are an integral part of a balanced engineering education.

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1. Introduction

Bachelor of Science degrees in the United States are 4-year programs, notwithstanding exceptions from private institutions such as Worcester Polytechnic Institute and Rochester Institute of Technology that offer 5-year degree programs. Engineering education has historically coped with that reality by requiring between 130 and 140 credits (or more) over 4 years, even though the standard for a Bachelor of Science degree is 120 credits. External pressures over the past 30 years have resulted in a progressive reduction of credits, aiming for the 120-credit standard. Over that same period, important fields of research in engineering have matured and received broad acceptance and adoption in our society. The field of robotics used to be pursued almost exclusively at the graduate level 20 years ago. Yet today, it is expected that robotics be an integral part of any undergraduate program in electrical engineering, mechanical engineering, computer science and numerous other fields.

The two opposing trends—increasing content while reducing credits—have been addressed by requiring a measure of independent, self-directed learning on the part of undergraduate students. ABET is the organization that accredits engineering programs in the United States and in 28 other countries. ABET is fully aware of this trend and—in keeping with the very nature of the engineering profession—it requires that graduates of an accredited program attain "a recognition of the need for, and an ability to engage in life-long learning" [1]. While specialized topics will continue to be explored in depth at the graduate level, engineers with a baccalaureate degree are expected to leverage the rapid dissemination of research results and emerging technologies as users and system integrators. In order to prepare engineers for this ever increasing dynamic environment, the current approach entails an initial exposure to a wide range of state-of-the-art topics during the last year or two of a student's undergraduate education by means of technical electives coupled with developing a robust ability to learn independently.

Self-directed learning, also called independent learning, is a method of learning that is not tied to a presentation or lecture by a specialist, but rather the product of the student initiative to search, locate and assimilate the information with minimum guidance from a specialist. This is expected for doctoral-level work, but not often seen at the baccalaureate level. Ready and quick access to an abundance of information over the internet has made this effort possible in ways that could not have been imagined 20 year ago.

This paper describes the experience of a technical elective course in robotics offered at the University of Southern Maine containing a substantive structured component of self-directed learning that includes coverage of the areas of artificial intelligence, machine learning, evolutionary robotics, and biomimetics. The experience is reported here by the instructor and by a student who completed the course in May of 2015. The paper is organized as follows: the next section provides a brief survey of related published work in the area; Section 3 addresses the academic experience of self-directed learning; Section 4 reports specific findings by the students who took the course; Section 5 discusses the development of soft skills; and Section 6 is our conclusion.

2. Related Work

Artificial intelligence, machine learning, evolutionary robotics and biomimetics are specific examples of relatively new topics in the technology field. In recent years, research on these topics has helped develop stronger fundamentals for everyone to learn from. These topics that were previously considered high-end doctoral work can now be studied and researched by undergraduate students. Research on these areas of artificial intelligence and learning began with discussions of the Markov Decision Process [2]. The Markov Decision Process was one of the first successful techniques used to mathematically quantify the topic of decision making. The Markov Decision Process is a stochastic process that operates similarly to a finite-state machine with the addition of probability and statistics. Research on fuzzy logic and fuzzy sets have also built the fundamentals of artificial intelligence [3]. Fuzzy logic is yet another way to quantify decision making with numerical and logical processes. Dynamic programming has provided a way of transferring these processes efficiently into machines for use in fields like robotics [4]. Without dynamic programming, decision making theories would be far behind where they are now. From these basic topics, new strategies were created that were more efficient and effective. Random Rapid Trees combine these previously developed topics to find path planning solutions for high degree-of-freedom systems [5]. The combination of all these previous research techniques has created new algorithms such as KiPLA (Kinodynamic Planning-Learning Algorithm) [6]. KiPLA uses the fundamentals of random trees and other decision making processes to create their Blind-RRT planner and Local Weighted Projection Regression techniques. Topics like Voronoi Diagrams are now considered fundamental and have led to the development of fast marching algorithms such as the Fast Marching Square method [7][8]. Neural networks use many of these simple ideas to create a complex brain-like approach to solving problems [9]. The Pioneer 3DX robot is yet another state-of-the-art piece of technology using fuzzy logic [10]. The MANFRED is an adaptive evolutionary robot that uses all of the above subjects [11]. Robot memory is another subject that has been researched to help develop towards the goal of creating a full AI system [12]. Even while these topics are quite complex, they are all built upon the fundamentals mentioned above.

3. Classroom Experience

ABET requires that engineering graduates attain 11 Student Learning Outcomes, labeled a-k. In addition to the expected outcomes of a technical nature for an engineer, such as mathematics and science fundamentals, conducting experiments, designing under realistic constraints, and the use of techniques, skills and tools, we highlight 6 outcomes that are of a professional nature, often referred to as *soft skills*:

d) function effectively on teams involving students from diverse backgrounds;

f) understand the professional and ethical responsibilities of a practicing engineer;

g) communicate effectively in oral, written, graphical and visual ways;

h) understand the role and impact of engineering solutions in the broader societal context;

i) recognize the need for and engage in self-directed learning; and

j) gain knowledge and understanding of contemporary issues [13].

The course being reported is EGN 317 Introduction to Robotics. It was delivered most recently in the spring of 2015, with an enrollment of 28 students. The course has the following catalog description:

> *Kinematic modeling of serial manipulators. Trajectory, path and motion planning. Actuators and sensors, artificial intelligence, and programming of robotic devices. Examples of multiple platforms in the Robotics and Intelligence Systems Laboratory* [14].

EGN 317 is a senior-level technical elective for computer, electrical, and mechanical engineering students, with differential equations, linear algebra, and introductory computer programming as prerequisites.

The self-directed learning experience was designed to advance the 6 ABET outcomes mentioned above in addition to the core technical content of the course. It started with the premise that a single introductory course cannot deliver the breadth of applications that are currently being pursued under the umbrella of robotics in a traditional lecture format. The experience consisted of two parts. A group research project was carried out in the first half of the semester followed by an individual book report due at the end of the semester.

3.1 Group Research Project

The project began with the identification of current areas of interest in robotics. A combination of prior experience by the instructor and input from the students resulted in the following list of topics:

1. Military applications;
2. Industrial applications;
3. Space, underwater and hazardous environments;
4. Biomimetics and evolutionary robotics;
5. Entertainment and competitions;
6. Micro and nanoscale applications;
7. Medical applications;
8. Consumer and home products; and
9. Search and rescue applications.

The class proceeded to form groups of 4 students that were self-selected based on personal interests. The first 7 topics of the list above were selected. The students were tasked to research their assigned topic in sufficient depth as a group over the course of one month and deliver a presentation for the rest of the class. Students were each exposed to all topics researched, and to one topic in greater depth. To ensure the engagement of every student in the experience, the students in the audience filled out an evaluation form for every presentation. The forms were collected and, after redacting the evaluator name, were distributed back to the students so they could use them to improve their presentation skills. Each group was also required to deliver a full technical report, following the ANSI/NISO standard [15]. In order to assess how well the students worked together as a group, group dynamics was evaluated using the CATME instrument [16]. Finally, a one-page self-assessment was submitted to give every student the opportunity to reflect on his/her experience. The students worked on the assignment for a period of 8 weeks, from the selection of topics to the final self-assessment. However, only 2 weeks of class time were dedicated to the assignment, including instructions, progress checking and the presentations.

3.2 Individual Book Report

For the second self-directed learning experience, each student selected a book from a list of pre-approved books, or they could propose a book containing sufficient technical content for approval by the instructor. Every student presented a book summary and analysis to the class near the end of the semester, while the other students evaluated using the same instrument utilized for the presentations. A technical report was delivered and a self-assessment was completed by the students. The books were selected at the beginning of the semester, giving the students over 3 months to locate, acquire, read the book, and prepare the presentation. Although the second experience was not a group experience like the first and, as such, did not contribute to ABET's Student Learning Outcome d, it provided a second iteration of the research/present/ evaluate/reflect cycle that advanced all other ABET outcomes listed above. Significant improvements in presentation skills between the first and the second set of presentations were observed by the instructor and noted by students through the self-assessment instrument. The books that were selected covered a wide range of topics under the general framework of robotics.

4. Student Findings

In this section, we will summarize findings by the students who engaged in self-directed learning in various specific areas.

4.1 Artificial Intelligence

Artificial intelligence is the study and creation of machines that appear to exhibit intelligent behavior. Intelligence has never had a solid definition, but includes things like the ability to learn, understand, plan and memorize. The definition of intelligence can be simplified as the ability to process information and arrive at a decision. It can be said that most—if not all—human actions are intelligent. Therefore, the main focus of artificial intelligence is to mimic the intelligent behavior of humans through the use of a machine. Some divisions and focuses of artificial intelligence include planning, learning, logical reasoning and communication. Full AI is the goal of creating a machine that can successfully perform all human tasks. This is the eventual goal of artificial intelligence research. When artificial intelligence is applied to robotics, it is often discussed as the application of robotics to automatically perform human tasks in the physical world. This includes object manipulation and navigation

One of the student's findings was research involving IBM's *Watson*. *Watson* is a supercomputer that was created with the purpose of being able to answer any question it is given. While *Watson* does appear to have knowledge of everything, it is just a computer algorithm that scans through pages and pages of data to find the most suitable answer.

Some students explored the topic of localization, mapping, and path planning in mobile robotics. One of the most common methods for developing movement strategies for mobile robots is the Voronoi diagram. Voronoi diagrams take map data, often captured from sensors such as sonar or LIDAR, and create a connectivity graph in order to determine the best possible route to the goal location. The Voronoi diagram is a simple idea that has created many complex AI systems.

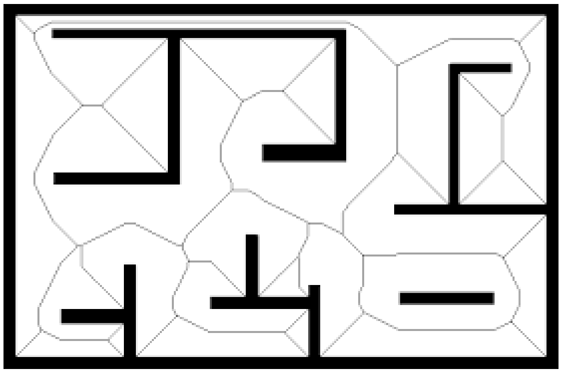

Fig. 1. Sample Voronoi Diagram

The Voronoi diagram is a construction of lines that follow the midpoint along all paths of the map. Every point on the line of a Voronoi diagram is equidistant to two or more obstacles. Robots can use this line to navigate through passageways to get to their goal. Figure 1 shows an example of a Voronoi diagram on a small surface map made up of open spaces and obstacles [17].

One student investigated the RHINO mobile robotic system. This system starts by developing a map from sonar sensor readings. It then creates a Voronoi diagram similar to the one above. Next, it uses algorithms to determine critical points on the map (junctions). From there, it creates a topological map like the one in Figure 2 [18]. By moving from node to node a robot can reach its goal. This map can now replace the original Voronoi diagram, requiring only a few data points rather than the representation of a line. This is just one example of how a fundamental principle of artificial intelligence can be developed into an effective path planning technique.

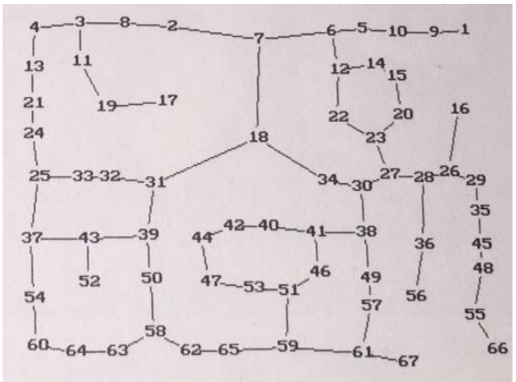

Fig. 2. RHINO Topological Map

4.2 Machine Learning

Machine learning is a specific area of artificial intelligence. Machine learning is the study of computer programs that automatically enhance their decision making based on previous inputs. Machine learning is closely tied to pattern recognition and statistics. The goal of machine learning is to produce decision making that is similar to that of humans. Humans make decisions naturally through the processes of comparing and contrasting, grouping information, ranking information and using previous experiences to constantly manipulate previous decision-making processes. Machine learning is the mathematical representation of these strategies to allow a machine to make better decisions through continuous adaptation.

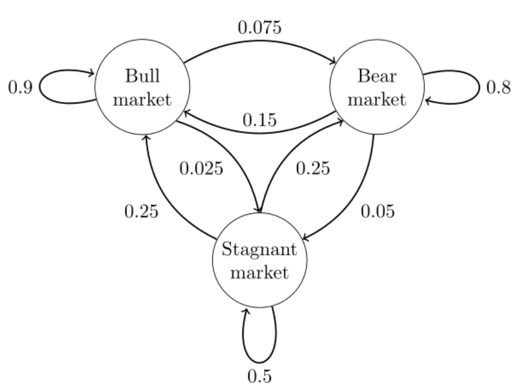

Fig. 3. Markov Model

One machine learning topic a student explored was the Hidden Markov Model. The normal Markov Model uses different states to make decisions. An example of a Markov Model can be seen in Figure 3 [19]. This Markov strategy is being applied to the stock market to determine the current state of the economy. This same strategy can also be used to determine the state of a robot. The Hidden Markov Model has hidden or unknown states. This model is the basis for many algorithms in neural engineering or neural networks. Neural engineering is the creation of genetic algorithms aimed at mimicking the brain's decision-making process. As such, it is an area where artificial intelligence and biomimetics intersect.

4.3 Evolutionary Robotics

Evolutionary robotics is the study of robot control that uses machine learning to make the decision making process of the robot faster and/or more accurate. It follows the paradigm of random mutation and natural selection to produce the next generation of an "evolved" process. Evolutionary robotics could also refer to the adaptation of kinematics or physical structure to better perform the task at hand. Other than improving speed and accuracy, one goal of evolutionary robotics is to have a single robot learn multiple tasks. This field of robotics may eventually produce multi-purpose or all-purpose robots.

Students explored the topic of self-organization of robots, meaning that the robot itself determines how it makes its decisions rather than a set of pre-fixed algorithms or steps. In other words, the path between input and output is dynamic.

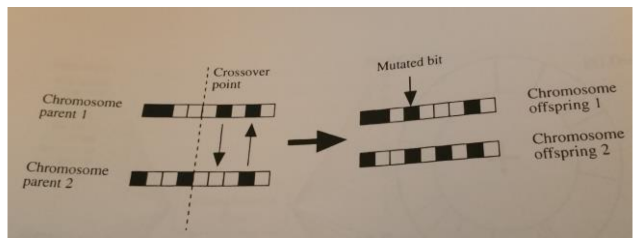

Fig. 4. Crossover and Mutation Technique

The crossover and mutation technique for evolutionary robotics was explored by the students. Decision bits are crossed and then mutated to create new decisions that determine the robots operation. An illustration of this technique can be seen in Figure 4 [20]. It was directly built from the natural process of genetic crossover. This process creates an uncertain output at each iteration.

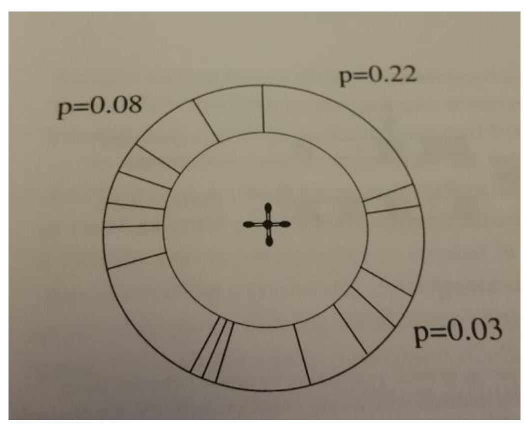

Fig. 5. Roulette Wheel Technique

The roulette wheel is a strategy of probability that is constantly adapting based on previous decisions. As new data is acquired, it morphs the probability that affects the robot's decision making. Figure 5 shows a visual representation of the roulette wheel [19]. This wheel is constantly updated as feedback is delivered to the system. The next decision is made randomly by "spinning" the wheel. The decisions that are the most successful will eventually gain a larger space on the wheel.

Lastly, some students explored the action and evaluation model. The model is commonly used in many algorithms, not only in robotics, but also in the stock market and on flight path estimation. The process is as follows: the robot guesses its next action based on probability. Once the ideal action is discovered, it is compared to what was done originally. This information is used to update the model. This is the basic process behind almost every evolutionary system.

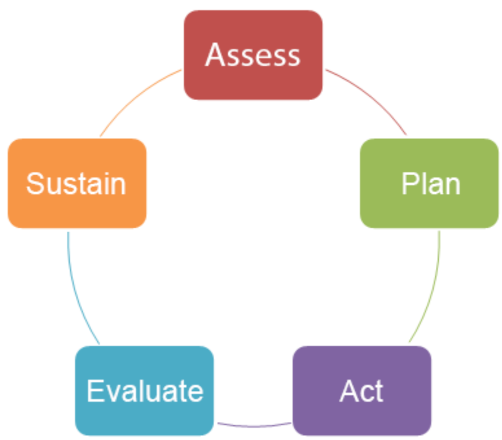

Fig. 6. Evolutionary Process

This system is not necessarily unique to just robotics. Evolutionary systems have been used in business strategies for years. Figure 6 shows a sample flow chart of an evolutionary business strategy [21]. The process starts with an initial assessment that leads to a plan. This plan is acted upon and then evaluated. The strategy is sustained until a reassessment is made. This is also the natural process that humans go through in order to make decisions. Both consciously and subconsciously, we evaluate everything we have ever done and it factors into our next action. Evolutionary robotics implements the same process that has been so successful in other tasks and applies them to robotics.

4.4 Biomimetics

Biomimetics is the study and development of devices and systems that mimic the natural behavior and characteristics of living organisms, thus "imitating biology". A typical example is the commercial product called Velcro. Velcro is the invention of Georges de Mestral, a Swiss electrical engineer who in 1941 went for a walk in the woods and wondered if the burrs that clung to his trousers could be turned into something useful [22].

Biomimetics also includes the development of synthetic polymers that hold similar structures to natural materials like DNA. Biomimetics thrives behind the idea that nature has created the most efficient systems over multiple generations and we may copy these systems to solve human problems. Natural selection has improved species by weeding out inefficiencies. Biomimetics takes advantage of the natural "redesigns" of the world.

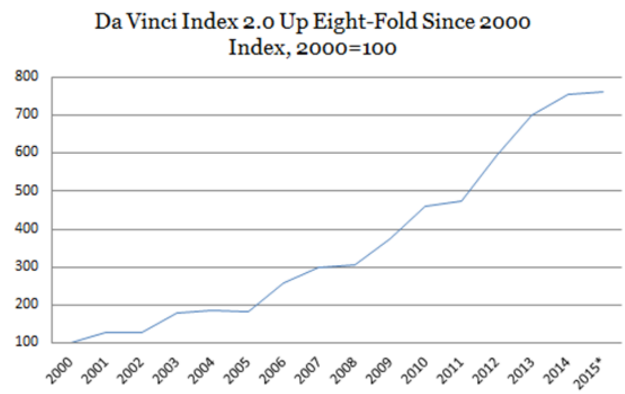

Fig. 7. Da Vinci Index

The focus of the students' research was on the use of biomimetics in robotics and the potential impact these devices can have to our society. This included both humanoid robots and animal robots. Students discovered the Da Vinci index, which tracks all advances in biomimetics. This index is a good indication of the progress that has been made in the field. Figure 7 has the latest (2014) chart showing the growth in biomimetics using the Da Vinci index [23]. Biomimetics research continues to grow exponentially.

Fig. 8. Naro

Students discovered many biomimetic robots, including *Naro*. *Naro* is a robot designed after the tuna fish (Figure 8). Tuna have a specific shape and kinematic movement that allows them to move through water quickly. When creating this robot, these features were mimicked to create a more effective machine.

Naro-Tartaruga is a robot designed after a sea turtle. Figure 9 shows a computer model and a built prototype. *Naro-*

Tartaruga uses independent actuators to mimic the motion of a sea turtle's flipper to propel itself. If perfected, this turtle could be used in many applications, including surveillance of humans or surveillance of wildlife with minimum disturbance.

Fig. 9. Naro-Tartaruga, Concept vs. Actual

Students also discovered aerial biomimetics. The Ornithopter is a bird like robot that uses flapping motions to travel (Figure 10). This is contradictory to most flying machinery we have now that have fixed wings combined with propulsion to create lift.

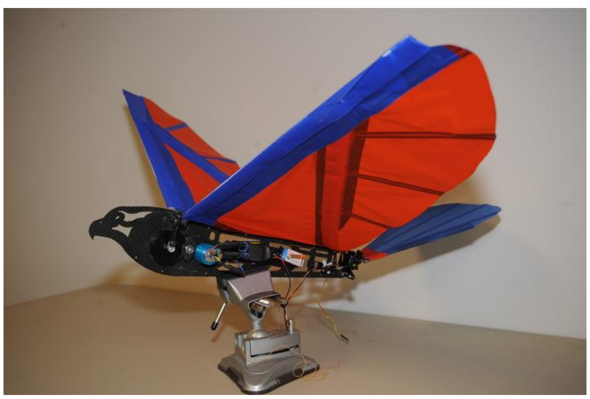

Fig. 10. Ornithopter

The most popular biomimetic robot researched was the snake-like robot. Many snake robots have been designed that use completely independent links to create a fully functional and flexible robot. Carnegie-Melon's snake-bot is shown in Figure 11. This research is important to the medical community because smaller versions of these snake robots can be used for minimally-invasive surgeries or cavity probes.

Fig. 11. Snake-bot

4.5 Entertainment

Robotics is gaining a larger role in entertainment year after year. Students have explored the various ways robots are being used for recreation. One robot explored was the AirDog (Figure 12). The AirDog is an aerial robot that has a camera and will follow you around. The AirDog is one of many personal drone cameras that are coming on the market [24].

Fig. 12. AirDog

Robotic cameras are not only used for personal use, but professionally as well. The SkyCam, shown in Figure 13 is a professional grade camera robot that is used to record sporting events. The SkyCam is different than most robots because it is controlled by a series of cables that determine its position. The SkyCam was one of the first robotic cameras used for aerial shots [25], but now many other cameras are available on the market.

Fig. 13. SkyCam

Not only are robots used to watch and record sports, some are used to play sports. Many robots are built to emulate humans playing sports. The most popular sport played by robots is soccer. Figure 14 is a photo of robots playing soccer in the RoboCup [26]. Soccer robots have become so popular that the RoboCup was created to have them compete against one another. The RoboCup has multiple categories and international competitions.

Soccer is not the only sport that robots play. Robots have been built for golf, dancing, gymnastics, baseball, and many other sports.

Fig. 14. RoboCup

4.6 Medical Applications

Biotechnology is one the fastest growing technology fields in the world today. Over the past few decades, robotics has been applied to the medical field with hopes to do things that were not possible before.

Fig. 15. Da Vinci system

The da Vinci Surgical System shown in Figure 15 is a robotic teleoperation system that allows surgeons to perform a virtual surgery through an interface station while the robot does the physical surgery. This system is incredible because of its future potential. It could allow all medical personnel to be outside of the operating room. This would mean a less contaminated environment. Not only would surgeons not need to be in the room, surgeons could potentially be across the country and beyond. This would be extremely beneficial for emergency surgeries that need to be performed by specialists that are not in the area. The robot provides real time sensory feedback to the surgeon while the surgery is being performed. This allows for the surgeon to have a similar feel when compared to normal surgery. The da Vinci system has been in use since 2000 with great success [27].

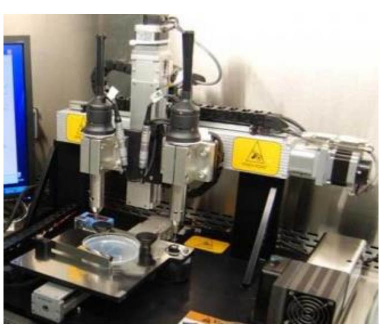

Fig. 16. Navogen MMX 3D bioprinter

A new technology in the robotics field is the 3D bioprinter [28]. The 3D bioprinter (Figure 16) is very similar to a 3D printer, except it prints biological materials. These materials could include artificial skin grafts or even organs. Future improvements on the 3D bioprinter could have a huge impact on the medical field.

4.7 Military Applications

Robotics is now becoming a part of the military as a way to protect humans by putting robots in the line of fire first. Current robots are mostly used for surveillance purposes, but some students explored some unique robots being used in the military. The C-RAM system shown in Figure 17 is a missile defense system that automatically aims defense weaponry. This system was used in Iraq and has saved many lives [29].

Fig. 17. C-RAM

TALOS is a robotic exoskeleton that is designed to be used in combat applications. The goal of the TALOS system is to eventually have a full body suit that is bullet proof and weaponized [30]. Suits like the one shown in Figure 18 will help give robotic like reliability to soldiers, while leaving the human brain in control.

Fig. 18. TALOS

4.8 Space Applications

Robotics has been used in space ever since space exploration began. Rovers have been used to explore the moon and mars for decades. However, the Robonaut 2 shown in Figure 19 is a different type of robot that NASA has been developing. The Robonaut is a human like robot that is intended to assist astronauts while in space. The Robonaut would be able to do dangerous external maintenance on space shuttles and the International Space Station in order to keep astronauts away from high-risk environments [31].

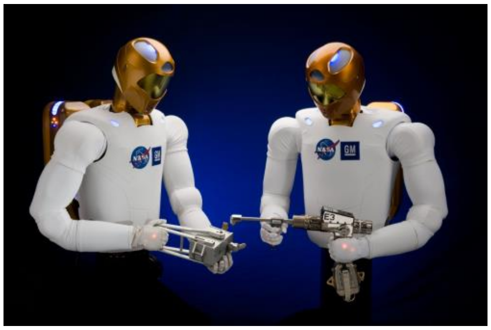

Fig. 19. Robonaut 2

4.9 Micro- and Nano-Scale Applications

Harvard is home to some of the most advanced research in micro and nanorobotics [32]. While micro and nanorobots cannot do much on their own, together they can complete very difficult tasks. This idea is called swarm robotics. Figure 20 shows many tiny robots built at Harvard combining to form a wrench shape. The goal of future swarm robotics research is to get these tiny robots to work together just like a swarm of bees or a colony of ants to accomplish specified goals.

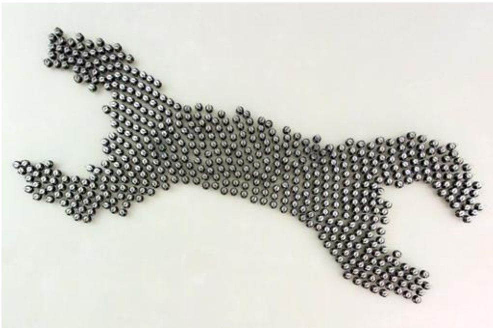

Fig. 20. Harvard swarm robots

While all of these robots researched by students are very different, they are built in a very similar way. They are all built using the fundamentals of robotics and artificial intelligence explored earlier in this paper. By thoroughly understanding the basics of robotics and computing, students can understand how all these complex robots work, and how simple they actually are.

5. Soft Skills

In addition to the primary soft skill of self-directed learning, the students had the opportunity to learn and practice other valuable soft skills. Teamwork was promoted within the group project while exposure to ethics, contemporary issues, and the impact of engineering solutions were embedded in all activities. One of the difficulties in assessing those skills in general is the fact that every student will learn something different when asked to learn independently. Assessment was made possible by a series of questions that required verbal articulation of the results. Rather than explain what was learned from the instructor's point of view, we present a series of student quotes that were extracted from four different instruments to illustrate the quality of the learning experience.

Instrument #1: CATME survey

"The team worked well together and we were able to work individually on our topics; however we also were able to research, work on the presentation, and work on the paper together for a positive collaborative experience."

"Each of our group members had comparable expectations as to the amount of effort this project would take and what would be an acceptable outcome. This created a very harmonious collaboration. Every group member was self-motivated and, although we met regularly, it was not necessary to micro-manage anyone on the team. All in all, this project was a great opportunity to work with some new people."

Instrument #2: Presentation self-assessment

"The individual part of this experience went well for me, that being, the independent research part. I learned a lot and enjoyed learning about those things. I like learning about modern/post-modern robotics as it is very challenging to understand and it is at the cutting edge of technology today. I say post-modern because a lot of the info that was spoken about in my group's presentation on biomimetics is still in its infantile stage. The information is still not fully developed yet and in some cases, like my subtopic on ornithopters, the information and theories have not even been verified and tested yet. By studying this stuff on the ground level it really allows me to understand the basics and then hopefully allow me to further developments in robotics throughout my career."

"The presentation process was different than most presentations I have done. I have yet to do many presentations on technical topics. The difficulty with technical topics is deciding how in depth to go. Having few technical details leaves your audience wishing there was more. And having to many either bores your audience, or confuses them. It was good to gain more technical presentation skills because these will most likely be the types of presentations I will be doing in the future."

"I really thought delving into the chosen topics on the internet was a great way to learn more about our topics in a very fast way. I thought the actual internet search went well and the typing of the report and class presentation was a good way to accomplish a knowledge on a wide range of topics. Listening to the other groups and grading them was also a very good method of getting the class involved and learning a lot in a short amount of time. The presentations on a whole were very interesting to listen to."

"The biggest thing that went well in this experience is the quality of the information covered. Robotics has a wide variety of applications, and our group did a great job at providing an overview of the topic, from its beginnings, past and current projects, as well as gazing forward to see what lies in the future. As shown below, it was hard to do this in the time allotted, but a presentation of this material could have gone on and on… Overall our slides were well put together and everyone showed interest in the topics of research."

"This assignment is a great learning experience, because it covers independent study, teamwork, and public speaking. Most importantly, I enjoyed the opportunity to choose our area of research, which allowed me to gain valuable knowledge that can be directly applied to my field of study."

Instrument #3: Book report self-assessment

"In the internet presentation I did not speak clearly according to those evaluations, according to the evaluations for the book report presentations I improved immensely in my speaking."

"What went best for me on this assignment was my understanding and perspective of societal implications and the economics that drive robotics design and implementation. Specifically, the biggest takeaway for me was the suggested laws for organizational implementation of robotics and how they can affect the workforce, business and general public in a number of manners. Namely, there could be positive and negative repercussions financially, ethically, and monetarily."

"In this experience I learned a lot about topics outside our class. I did not learn about mathematics or how to actually implement the strategies discussed in my book, but I learned about what could be done. I found it beneficial that I chose a book that had so many different examples to discover."

"The oral presentation was not as polished as I would have liked it to be. I spent more time in reading the book and preparing the technical report. I would have preferred to spend more time in practicing the presentation."

Instrument #4: Final exam

"A lot of the marine biomimetic robots are being studied and actually being used as flying biomimetic robots as well."

"Through both assignments I learned a lot about public speaking. I was able to improve greatly from the first presentation to the second. I also learned a lot about ornithopters in the internet presentation."

"Talking about versatile robots again, the snake-bots are super-cool and super capable. While many robots will be made to operate in a world made for humans, we shouldn't be blind to robots of other forms. Biomimetics will be a growing field."

"I learned that aside from contemporary issues with design, programming, and implementation, there are a lot of considerations that need to be made with regard to economic, moral, ethical, and social implications."

"Medical bots like Watson are already a trusted source for cancer treatment recommendations and have better outcomes than most human-doctor treatment recommendations."

"The internet survey gave me the opportunity to really explore decentralized AI and how group processing in microbots can be used to accomplish huge tasks."

6. Conclusion

The title of this paper ends with a question mark. Yes, self-directed learning is a meaningful and effective vehicle to expose students to a wide range of topics in an introductory robotics course at the baccalaureate level. Yet it is also true that the diversity and the popularity of robotics are very effective vehicles to train students in the skill of self-directed learning and to promote the notion that a competent professional in our modern society must become a life-long learner. This paper reports the encouraging results of the experience with one such course.

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