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Educational robotics: using the Lego Mindstorms NXT platform for increasing high school STEM education

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EDUCATIONAL ROBOTICS:
USING THE LEGO MINDSTORMS NXT PLATFORM
FOR INCREASING HIGH SCHOOL STEM EDUCATION

by

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ABSTRACT

The field of educational robotics (ER) seeks to use the building and programming of robots to engage and educate the next generation of college freshman entering science and engineering majors. To increase the rate of application to science and engineering degree programs as well as the rate of retention, students must be engaged in high school. They must acquire the knowledge and interest to pursue these career choices. This research explores the use of robotics to interest high school students in science, technology, engineering, and math (STEM) and to improve their knowledge of these subjects. The case study developed instructional strategies to guide the learning process, increase students' understanding of concepts and their practical application, and consequently increase their interest in STEM college majors and career paths. The instructional strategies explored in this research required students to study a given set of concepts, restate the newly acquired knowledge, apply it in a practical hands-on activity, and review the significant points made by the instructor. This research used the Lego Mindstorms NXT robotic platform to permit practical application of the training process to the Botball robotics competition. Students involved in this case study demonstrated improvement in application of science and mathematics principles to robotics and won the regional Botball competition after completing the training.

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1. INTRODUCTION

The foremost subfield of engineering education research used to engage K-12 students in engineering is educational robotics. The world is in a state of constant flux, with access to information and technology increasing steadily. With each passing year, therefore, the need grows to prepare students for a technological culture that demands problem solving skills, new ideas, and innovative products. The need to increase interest in STEM skills has led the National Science Foundation to fund programs designed to raise the numbers of undergraduate students recruited and retained in engineering (Boykin, 2010). Increasing interest in engineering is especially important as engineering departments are reporting relative declines in enrollment and freshmen are entering college without the prerequisites necessary to succeed in engineering majors. Inadequate preparation leads students to drop out of school or transfer to non-engineering majors (Karp, 2010). The attrition rate of forty percent nationally in engineering majors is caused in part by the low level of practical engineering experience gained by engineering students in the first two years of college (NSF, 2007). The field of engineering is not attracting enough students of sufficiently diverse backgrounds (NSF, 2007). ER has successfully improved lifelong learning and intellectual skills by teaching the practical applications of robotics, connecting them with the foundational principles of mathematics and science. Both conceptual and hands-on learning are encouraged and rewarded. Since the future of engineering is in the recruitment and training of new engineers, this study sought to determine how best to use ER within the framework of the actor-oriented model (Lobato, 2003) of the transfer of learning.

2. RATIONALE

To improve the performance of high school students in STEM disciplines and to raise retention rates for engineering college freshman through educational robotics, procedures must be developed to engage the students in a learning process that extends beyond surface knowledge of robotics to reach a deeper understanding of the underlying concepts.

2.1. GOAL

The main goal of this research was to determine how the constraints of training experiences and the environment in which they are conducted affect the learning process. These constraints shape the process of acquiring advanced robotics knowledge and, with minimal instruction and oversight, help high school students build a strong knowledge base and transfer it to skills required by robotics competitions. Instructor oversight enhances the cumulative knowledge and energy of the group dynamics to help high school students master advanced robotics techniques. By providing instruction in robotics-related topics, offering structured training exercises, and giving students an avenue for the exploration of concepts, this research analyzed the improvement in students' ability to apply knowledge to associated STEM tasks.

2.2. OBJECTIVES

This project had the following objectives:

- Identify areas of conceptual knowledge that applies to robotics for inclusion in the learning modules supporting instructional strategies.
- Adapt for high school students teaching exercises and activities from coursework taught to upper-class students of advanced robotics.
- Evaluate the effectiveness of these teaching exercises based on student mastery of the concepts.
- Evaluate the ability of students to apply conceptual knowledge to hands-on robotics-related tasks.
- Measure the degree to which hands-on activities students' skills and prepare them for an educational robotics competition.
- Evaluate the impact of the developed conceptual training on students' interest in and perception of STEM careers.

3. LITERATURE REVIEW

Much research has sought to identify the perfect vehicle to transfer knowledge of science and math to high school students. According to the American Association for the Advancement of Science (1993), the practical application of scientific knowledge is most promising. Nason and Woodruf (2003) gave greater weight to this claim when they argued that providing a context for a problem or requiring the application of principles enables students to develop a deeper understanding of mathematics. This section presents constructionism as the base for inquiry-based learning for ER.

The science of engineering education research applied to the transfer of learning to students has its roots in the work of Thorndike and Woodworth (1901). Their theory, called identical elements, proposed that transfer occurs only when two tasks share identical elements (Royer et al., 2005). This theory, and subsequent research on stimulus generalization, was limited in scope because it ignored the possibility of transfer when stimuli differ (Royer et al., 2005). With the cognitive theory revolution of the late 20th century, multiple expanded views of transfer attempted to remedy the limitations of the identical elements theory. Lobato (2003) offered the most complete summarizing model of these expanded views of transfer and identified the transfer mechanism (Royer et. al., 2005). Lobato's actor-oriented transfer model evaluates "the personal construction of relations of similarity across activities (i.e., seeing situations as the same)" (Lobato, 2003, p. 4). Seymour Papert (1980) called knowledge transfer that emphasizes a student's inquiry-based study constructionism. According to Papert (1980), constructionism requires students to learn by making. He notes that new technology offers many opportunities for the practical application of mathematics. He argues that the most significant problems with traditional education techniques are: a) the lack of flexibility to adapt to different learning styles and personal projects/hobbies and b) a lack of knowledge on the part of the learner of how to apply educational material to real-life problems (Papert, 1980). To teach within the framework of constructionism, Papert (1993) suggested that students need a tangible means to think with. His solution was the LOGO project to teach mathematics through programming (Papert, 1993). Papert's LOGO work gave rise to many studies and educational developments, the most prominent being LEGO Mindstorms robots (LEGO group, 2006).

ER offers just such a problem-driven learning environment to provide the means for the students to explore and build. This focus of ER on problem solving in learning has been a major attracter for use in engineering educational research design, since the field of engineering likewise emphasizes the application of scientific principles to the design process (Lou; Liu; Shih; Tseng, 2010). The field of ER in characterized by four approaches or trends: (1) a "technocentric approach targeting the development of technical situations often close to the industrial world," (2) the formation of "microworlds" to recreate a learner's project, (3) computer assisted experimentation, and (4) programming (Brigitte, 2001). This research focuses on the second approach: the formation of "microworlds" to recreate a learner's project through inquiry-based learning (Williams; Ma; Prejean; Ford; Lai, 2007) to prepare increase interest in engineering careers.

Whitman and Witherspoon (2003) demonstrated the use of constructionism in ER by teaching instructors and students from middle school through college to integrate technology into STEM education. They presented a case study that explored the combination of computer-based learning and hands-on activities using the Lego Mindstorms robotics platform. Learners received an introduction to engineering and manufacturing and were then instructed to run a Lego airplane factory simulation. The simulation required that the learners assemble toy airplanes in several different factory configurations to improve the understanding and appreciation of technology and STEM subjects. Oppliger et al. (2007) explored cross-discipline problem solving in high school classrooms to encourage students to pursue STEM careers. Combining three learning environments -- the Aqua Terra Tech Enterprise, the Aerospace Enterprise, and the FIRST Robotics Enterprise – they proposed that problem-based learning can provide the means of meeting core high school mathematics and science graduation requirements. Matkins et al. (2008) looked at the effect on students' attitudes toward science and mathematics of robotics camps and in-class school projects. They indicated the students learned to work together and gained confidence through the program and the assistance of mentors.

Shymansky et al. (2008) studied pedagogy targeting "under-represented, underserved, rural, isolated school districts" science programs to address waning interest and low student achievement. Stein and Nickerson (2004) used ER to improve the interest and the understanding of usefulness of engineering middle and high school girls.

Karp et al. (2010) explored the use of Lego Mindstorms as an outreach tool for college engineering programs to improve retention rates. They had college freshmen teach robotics to K-12 students, and they promoted STEM-related careers to younger students by encouraging their interest in the material and connecting them with college students pursuing STEM careers. Freshman engineering students from Texas Tech University participated in the program as mentors for elementary school students. The outreach program learners were engaged in "engineering-related problem statements through exciting challenges so that they perceive STEM topics as being interesting and exciting" (Karp et al., 2010, p. 2). The curriculum used for the course was the elementary outreach activity program called GEAR (Getting Excited About Robotics, 2009). Several studies have used the Lego Mindstorm robotics platform of programmable bricks (Sargent; Resnick; Martin; Silverman, 1996) to teach robotics to K-12 students, developing problem-solving skills and teaching STEM concepts through technology-based activities (Norton, 2004).

Another ER platform built on the concept of programmable bricks is the Botball competition (Botball Group, 2009) organized by the KISS Institute of Practical Robotics (KIPR, 2011). The educational goals of the Botball competition are "teaching basic engineering principles, teaching team leadership and participation skills, applying math to robotics, and promoting awareness and teaching basic skills in computer programming" (Miller and Stein, 2001, p. 2). To engage and educate the students, this research studied the practical application of the inquiry-based learning to the high school robotics competition Botball to an after-school robotics club.

4. LEARNING MODULE SELECTION

In the design phase of this research, the most important task was the development of criteria for the inclusion of a concept in the training program. The goal was not to develop a complete curriculum, but to focus on the learning process; therefore, the number of learning modules was limited to three, selection of which is described below.

Topics for the training program were selected by evaluating robotics concepts against two sets of criteria. Topics included in the final list met all criteria developed from a review of the published sources. They are based on the knowledge gained by the author in high school and college. This selection process assumed that all students have similar experiences and that high school students will benefit from those of college students. The list of topics was developed from an evaluation of a college robotics courses and identification of those skills necessary to succeed in a Botball competition. The robotics courses evaluated are those traditionally offered to upper division or graduate engineering students. Interviews with members of the local high school robotics club were the basis for topic selection. Selections were based on the following questions:

- Has the concept been covered in robotics club training in past years?
- Is the concept important to working with robots?
- Does the application of the concept require mathematics and problem-solving skills?
- Would the concept have helped students to solve robotics problems encountered in past years?

The second set of selection criteria was generated based on a review of teaching techniques and topic selection methods reported in the literature. Topics that met the criteria had the following characteristics:

- Viewed as an important prerequisite for college.
- Combines both mathematics and engineering concepts (i.e. STEM concepts).
- Can be learned without instructor intervention.
- Can be packaged in a single learning module.
- Can be understood by the students in less than one hour.
- Linked to the fundamental skills necessary for performing well in the Botball competition.

After evaluation of each topic against both sets of criteria, three topics were selected for this case study: the mechanics of gearing, the dynamics of wheeled robots, motion control systems, and blob recognition for vision systems. Table 4.1 shows the original topic list and the rankings for each topic.

Table 4.1. Original Topic List and Rankings for Each Topic

Topic List	Selection Criteria Set 1						Selection Criteria Set 2					Total
	New concept material for students	Fundamental concept, not application overview	Needed previously but not taught	Previous instructor evaluation of helpful topics	Previous team member evaluation of helpful topics	Requires mathematics and problem-solving skills	Appropriate for independent learning	Can be addressed in one learning module	Require 45-60 minutes to complete	Viewed as beneficial in preparation for engineering	Fundamental Botball skill	
1.) Mechanics of Gearing	X	X			X	X	X	X	X	X	X	9
2.) Dynamics of Levers	X	X			X	X	X			X		6
3.) Dynamics of Wheeled Robots		X		X	X	X	X	X	X	X	X	9
4.) Motion Control Systems	X	X	X		X	X	X		X	X		8
5.) Line Following Techniques	X						X			X		3
6.) Obstacle Avoidance Techniques Using IR/Sonar	X		X	X				X	X	X		6
7.) Wall Following Techniques	X						X	X	X	X		5
8.) Blob Recognition for Vision Systems	X			X		X	X	X	X	X		7
9.) Obstacle Avoidance	X		X	X		X				X		5

4.1. TOPIC 1: MECHANICS OF GEARING

When reviewing the robotics courses at Missouri S&T, the mechanics of gearing was the first topic evaluated. Gearing and gear-based assemblies play a significant role in many mechanical systems; therefore, they are covered in introductory robotics, mechatronics, physics, dynamics, and related engineering design courses. Gearing mechanics have also been included in K-12 curricula [19]. The need to understand the mechanics of gearing was verified by interviewing the instructor for the 2010 robotics team at the local high school to determine the level of knowledge on the subject among high school students participating in this study who had also participated in the 2010 robotics team training. The instructor revealed that the students involved in the 2010 robotics group had not been trained in the use of gears in their final Botball robots. The instructor further noted that a better working knowledge of how to manipulate the motor output by balancing torque and speed would have been beneficial. One member of the 2010 robotics team also indicated that knowledge of gearing mechanics would have been valuable.

The topic of the mechanics of gearing was then evaluated against the second set of criteria. This topic was deemed a necessary part of the training because of the natural link between STEM knowledge and robotics. Gearing mechanics uses a geometric interpretation of the system, in a simple algebraic formula known as a gear ratio. The topic also introduces learners to the principles of force (and specifically torque) and speed. This topic was chosen based on its suitability for presentation in a one-hour training session. It also lends itself to the creation of demonstration assignments to support independent hearing and concept tutorials. Lastly, the topic is directly applicable to the Botball competition and to the learner's future robot development work.

4.2. TOPIC 2: DYNAMICS OF WHEELED ROBOTS

The second topic to be selected for inclusion in the training program was the dynamics of wheeled robots. This topic has immediate appeal because without knowledge of how to analyze and manipulate wheel dynamics, learners cannot construct a controllable robot. The topic has clear application to the Botball competition, which requires teams to navigate a closed course and precisely manipulate objects on a game board. Past robotics team members and their instructor indicated that the topic would be helpful for this year's Botball competition. Most students interviewed indicated a need to manipulate the robot more precisely, repeat action sequences given to the robot, and eliminate wheel slip. All three of these requirement fall under the heading of the dynamics of wheeled robots, and all are important in the college robotics curriculum.

The topic of dynamics of wheeled robots was also deemed important based on the second set of selection criteria. Wheel dynamics involves algebraic manipulation of physics equations. Further, calculation of the number of wheel rotations links robotics to geometry and trigonometry. This topic also introduces students to the essentials of programming robot drive motors. All material needed to introduce the topic can be covered in the one-hour training session, and it is useful in the Botball competition and for the practical application of physics, dynamics, and introductory electronics.

4.3. TOPIC 3: MOTION CONTROL

The third topic, motion control, is the most ambitious topic of those selected; it is an advanced topic even at the undergraduate engineering level. Motion control is the most difficult to package into a learning module for high school students given the level of mathematics and system modeling knowledge required to introduce control systems to college students. This difficulty aside, the topic has the greatest potential to benefit students by providing a foundation for the control of dynamic systems. As a combination of mathematics and engineering, motion control is the use of a controller to manipulate an input signal to create a desired output effect. It permits control of the velocity or position of a robot and all servos and motors. The full scope of motion control is too advanced for this training program; however, the mathematical model can be given to students. The concepts and application of the system involve mathematics that is covered in high school algebra classes. Past members of the local robotics team and their previous instructor spoke of the need to better understand how to accurately position a robot. This skill is of particular interest to the students participating in the Botball competition and because it can help eliminate sources of error by using the motion controllers to optimize the position of a robot and control the motion of robot appendices.

4.4. RESEARCH QUESTIONS

Three questions guided this research:

- To what degree does focused, conceptual training on STEM topics applied through robotics exercises improve students' skills in performing hands-on activities for an educational robotics competition?
- To what extent does application of concepts in a robotics competition stimulate and encourage learning in STEM fields?
- To what degree can conceptual and hands-on training in robotics improve students' STEM knowledge?

5. PROCEDURE

The following section details the procedure for conducting research and collecting data. The methods of preparing the learning modules created for this research are outlined and all data collection methodologies are reviewed.

5.1. ASSUMPTIONS FOR QUALITATIVE DESIGN

This research relied predominantly on qualitative analysis. Hoepfl (1997) synthesized the primary characteristics of qualitative analysis as described in literature over the last thirty years:

1. Qualitative research uses the natural setting as the source of data. The researcher observes, describes, and interprets settings as they are, maintaining what Patton calls an "empathic neutrality" (1990, p. 55).
2. The researcher acts as a human instrument of data collection.
3. Qualitative researchers rely primarily on inductive data analysis.
4. Qualitative research reports are descriptive, incorporating expressive language and the "presence of voice in the text" (Eisner, 1991, p. 36).
5. Qualitative research requires the researcher to determine the meaning of events for the individuals who experience them, and to interpret those meanings.
6. Qualitative researchers pay attention to the idiosyncratic as well as the pervasive, seeking the unique in each case.

7. Qualitative research has an emergent (as opposed to predetermined) design, and researchers focus on this emerging process as well as on the product of the research.
8. Qualitative research is judged using special criteria for trustworthiness (which are discussed in some detail in Sections 5.2 and 5.3.1).

The qualitative analysis presented here is supported by some quantitative data gathered from observations from the case study. These observations were recorded using scoring rubrics (Trochim, 2006).

5.2. DESIGN METHODS

The nature of the major questions posed by this research made the case study the most appropriate methodology (Case & Light, 2005). The strength of the case study lies in its focus on the context-driven nature of the knowledge (Case & Light, 2005). Given the small subject pool and limited time available for this research, a multi-year, large-group statistical analysis was not possible. The small-group structure, however, permitted a first-pass evaluation of the teaching strategies developed for this study.

5.3. STUDY BOUNDING AND DATA COLLECTION

5.3.1. Institutional Review Board Approval. All data gathered in this research was obtained by observing learner activities and collecting learner's opinions. The Missouri University of Science and Technology Institutional Review Board (IRB) approved the observations, the collection of performance indicators and survey results, and the interviewing of learners.

Safeguards were put in place to protect the identity of all participants. All research objectives were articulated to the participants, and written permission was obtained for the data collection procedures and the use of data collected in this study. Participant permission for the observation process was required acknowledging that observational research invades the privacy of the participant.

All data were collected using IRB-approved data collection instruments (presented in Appendix A.5 and A.6). All learners participated in an entry-level assessment (ELA) before the training program to measure their prior knowledge level of the robotics concepts that were covered in this study. Each training module included an overview document, a concept tutorial, an assignment worksheet document, and a concept evaluation rubric. After the conclusion of the training program, each learner was tested to compare the exit results with the ELA results.

5.3.2. Observation Scoring Rubric. All observations were quantified using rubrics with a five-point ranking scale: the benefit of the five-point psychometric scale is that it allows the respondent to indicate a neutral or indecisive response (Markusic, 2011). Rankings of "poor," "average," and "excellent" were replaced in each rubric item with an appropriate expression of the level of completeness or understanding as determined by the nature of the question. Figure 5.1 shows a sample rubric used in the first learning module. Appendix A presents a complete list of the scoring rubrics used in this research.

Hardware Training : Gearing Rubric

Instructor Name: Mathew Strautmann

Group Name: ____________________

Purpose: To allow the instructor to ascertain the level of group knowledge of the topic at hand.

Given to and when: Performed with Hardware group before starting Gearing Training and again at end of training to determine new level of knowledge.

Rubric format: Instructor verbal questioning of group members with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the participant seeing the rubric score.

CATEGORY	1	2	3	4	5
Identify different gear types such as spur, rack and pinion, worm, etc?	No Clue		Got lucky!		Identify Spur
	No Clue		Got lucky!		Identify Rack and Pinion
	No Clue		Got lucky!		Identify Worm
Explain how gears work	No Knowledge		Know it involves to gears touching		Understand Meshing
	No Knowledge		Know they are the point around the circle		Understand Teeth
Explain what a gear ratio is?	No Knowledge		Know formula but can't explain purpose or variables		Understand Formula
Explain the difference between force and speed?	Can't define either		Can define one		Can define both
	Can't determine either				Can determine both
Apply gear ratio theory to Botball?	Don't see use for gearing		Understand what a gear is but can't give application for the concept		Used it already, or would have been useful last year
Apply gear ratio theory in the future?	Not helpful at all		Understand it, but can't apply it		Understand it and can apply it

Figure 5.1. Gearing Evaluation Rubric

5.4. RESEARCH PROCEDURE

The following sections document chronologically the training and research procedure.

5.4.1. Entry-Level Assessment. The ELA analyzed the prior knowledge of each learner. This test focuses on STEM knowledge useful for working with robots and on those concepts deemed important for learners' ability to perform in educational robotics competitions. It included theoretical questions on terms and formulas and tested learners' ability to recognize situations where this knowledge can be applied to the Botball competition.

5.4.2. Training Module Overview. This phase was to provide learners with a clear overview of the tasks they would have to complete during each training module. The structure of each overview varied with each training modules, but all contained the following elements:

- Tutorial explaining the concept to be explored by learners in small groups.
- All groups took the entire tutorial, but each group was given a specific aspect of the concept to explore in greater depth.
- Group discussion followed the tutorial, and each group explained the aspect of the concept assigned to them.
- A final assessment was given to all groups to perform a practical concept-based demonstration (See 5.4.2.2, Training Module Assignments).

Following the training module overview, all small groups gathered for a review of the important topics from the module and any parts of the module about which learners were unsure.

5.4.2.1 Training module tutorial. To begin the transfer of STEM concepts to robotics, the students were introduced to the nomenclature and foundational concepts of the topic covered in the learning module. The purpose of the tutorial was to give the students a common vocabulary and to bring all students to the same level of knowledge. Both the vocabulary and knowledge level had been determined in advance based on the results of the results of the ELA and the requirements of the Botball competition. The tutorial was designed to lead students through the topic, helping them to recognize and apply the concept to different situations and problems.

5.4.2.2 Training module assignments. The knowledge transfer process took place in the assignment portion of the training module. This transfer process was a guided-inquiry process. Student had the flexibility to complete the assignment in any manner, but the instructor specified the environment and objectives.

Each small group completing the learning modules had to complete the same assignment set. Each was given a demonstration robot and instruction documenting the objective and tasks. The instructor functioned as a resource for the students, answering questions and clarifying issues when needed. Each group worked together as a team to apply the concepts from the learning module in a hardware-based problem. See APPENDIX A.5 for assignments.

5.4.2.3 Post test. To evaluate the conceptual knowledge transferred from the learning modules, a post-test was administered and the results were compared with the results of the ELA. The difference reflected the knowledge accumulated through the learning process and the extent to which pertinent robotic knowledge was transferred.

5.4.3. Setting. This study was conducted in Rolla, Missouri, a rural midwestern community that is home to Missouri S&T. The university provided the equipment and facilities.

5.4.3.1 Demographic characteristics. The participants in this study were high school students between 15 and 19 years old. The group included four male and two female students, all of whom were born in the United States. All were students at high schools in Rolla and surrounding small towns. Their involvement in this study was totally voluntary. The students were members of the Rolla Regional Robotics (RRR) team, formed locally in the summer of 2010 by mechanical engineering professor Dr. J. Keith Nisbett to teach students about robotics so that they could compete in the annual robotics competition, Botball. All interested members from the RRR were accepted as participants in this study. All volunteers signed a consent form allowing the researcher to observe and report on their experience; the consent form is presented in Appendix A.7.

5.4.3.2 Lab setup. This study was performed in a research laboratory equipped with workstations, each outfitted with Lego Mindstorm NXT robotics kits (Lego Group, 2011). See Figure 5.2 for sample configuration of the Lego Mindstorm NXT robot.

Figure 5.2. LEGO Mindstorms Line Following Robot

The NXT robot is operated by a packaged micro controller with multiple sensor inputs and outputs and the ability to upload programs written by the user. Many graphical and C/C++ programming software packages have been developed to write programs for the NXT (Hassenplug, 2011; National Instruments, 2011). This project used NXT-G, a graphical programming language designed to accommodate a short learning curve and permit easy graphical debugging. This language allows the students to focus on the application of concepts rather than on programming or debugging of code, aspects of robotics that were not part of this study (see Figure 5.3 for screenshot of NXT-G graphical programming language).

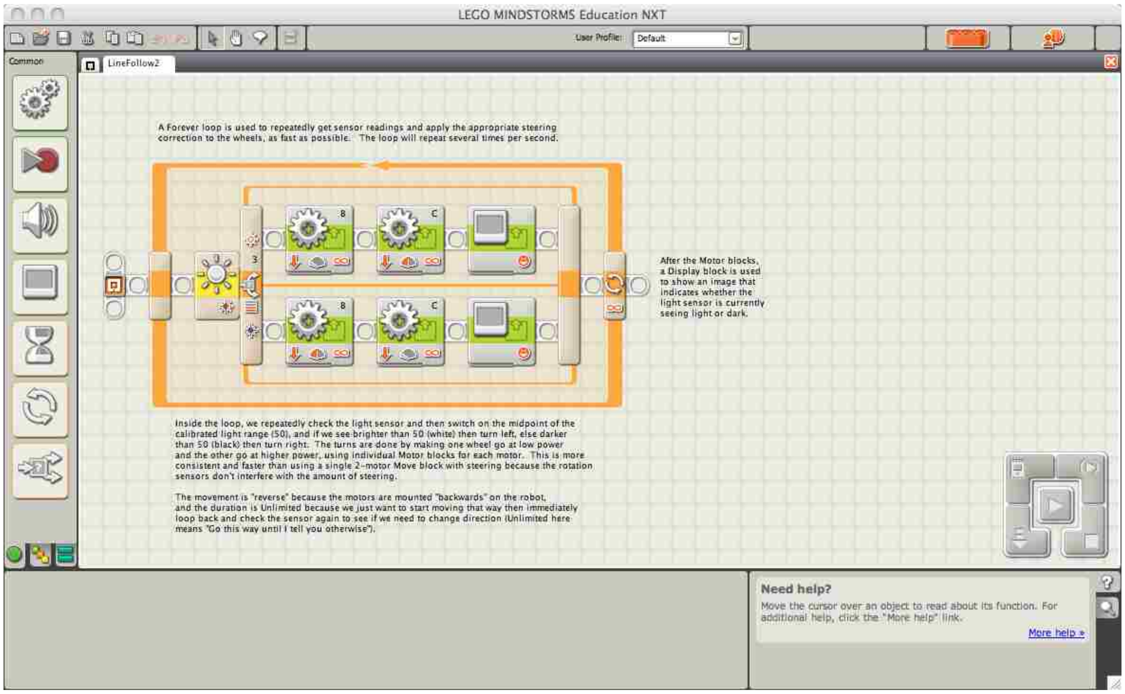


Figure 5.3. NXT-G Programming Language Screenshot

5.4.3.3 Data analysis procedure. Schatzman and Straus (1973) asserted that the analysis of qualitative data relies on the classification and coding of data in categories. The goal is to “identify and describe patterns and themes from the perspectives of the participant(s), then attempt to understand and explain these patterns and themes” (Agar, 1980, as quoted in Creswell, 1994). Throughout the data analysis process, data are continually organized, analyzed, and coded. The observations that emerge are recorded and further explored. In this study, data were sorted by chronological, categorical, and participant categories for organizational purposes.

5.4.4. Structure of Instructional Tasks. The following section details the created learning modules' student instruction sheets. Each learning module contained two instructional task sheets, an instruction overview and an assessment overview.

5.4.4.1 Learning modules instruction overview. The training program was divided into three independent learning modules, one for each concept covered. Each learning module began with the distribution of instruction sheets documenting the purpose of the module and the procedure for completing it. Figure 5.4 shows a sample instruction sheet from the first learning module. All instruction sheets used in this research are presented in Appendix A.5.

Intro: The purpose of the gearing overview is to explore how gears work and what they can be used for in robotics. It is not expected for you to master the material covered in this learning module the first time. Try to dig as deep as you can into the material and ask questions your team members and other facilitators as well. This worksheet will help you understand and apply the material about gearing.

Tutorial Link: Gear Tutorial

Instructions:

1. Read as a group the *Gear Tutorial* and watch both videos at the end of the tutorial.

2. Re-watch the gear video chosen at the beginning of this meeting by the random drawing and think about some of the following questions to aid in processing the video.

a. What types of gears are used?

b. Did the speed increase or decrease through the gearing?

c. Why do the gears turn different directions?

d. What type of devices would contain this type of gear assembly?

Figure 5.4. Gearing Module Overview Worksheet

5.4.4.2 Learning modules assessment overview. To guide the application phase of the learning module, each assignment was accomplished by an overview. Instruction sheets distributed at the beginning of each module explained the procedure for completing the assignment, which included a hands-on activity and the assessment questions. Figure 5.5 shows a sample assignment sheet from the first learning module. All assessment sheets used in this research are presented in Appendix A.5.

Procedure: Build a simple robot that can be programmed to go forwards and carry a load. The robot does not need to be able to turn left or right. The robot should be timed to travel in a straight line for 3 feet with two loads. Run one experiment with no load and a 1:1 gear ratio from the motor to the wheels, the second with no load and a high gear ratio of 4:1, the third with a 3lb load and a 1:1 gear ratio, and the four run with a 3lb load and a high gear ratio of 4:1. (Gear Ratio = Large gear diameter/Small gear diameter)

Example: Robot 1 with no load uses a motor that rotates at 10 revolutions a minute. The motor shaft has a diameter of 10 mm gear on it, and the gear connected to the wheel is 30 mm. The gear ratio would be 3:1, and the resulting velocity would be 30 revolutions a minute.

Student Activity: Write a program that makes the robot go forward three feet and then stop. Run each program, record the time required for the robot to cover the three feet and then compare the time trials. (Return the robot to the starting position after each run.) After running the program four times, answer the questions at the bottom of the worksheet.

Gearing Group #_______ Start Time: __________ End Time: ___________

How many revolutions did the motor complete in the 3ft test?

Figure 5.5. Gearing Assessment Worksheet

6. RESULTS AND DISCUSSION

To analyze the effectiveness of the training, a survey was used to ask students how much they felt they had learned using a Likert scale with 1 (indicating no improvement) to 5 (indicating much improved). The nine-question survey (see Appendix A.6.3) was administered to collect students' responses pre-training and post-training. The overall mean score for all nine questions increased from pre to post-training but the increase was not statistically significant, $F(1,10) = 4.54$, $p = .12$. Similar results were obtained when the analysis was made on the three main categories of questions, mechanics of gearing, wheel dynamics and respectively motion control. The mean value of the students' answers to each question group was seen to increase in the post-training over the pre-training but the increase was not significant. Each question-grouping mean value is summarized in Figure 6.1.

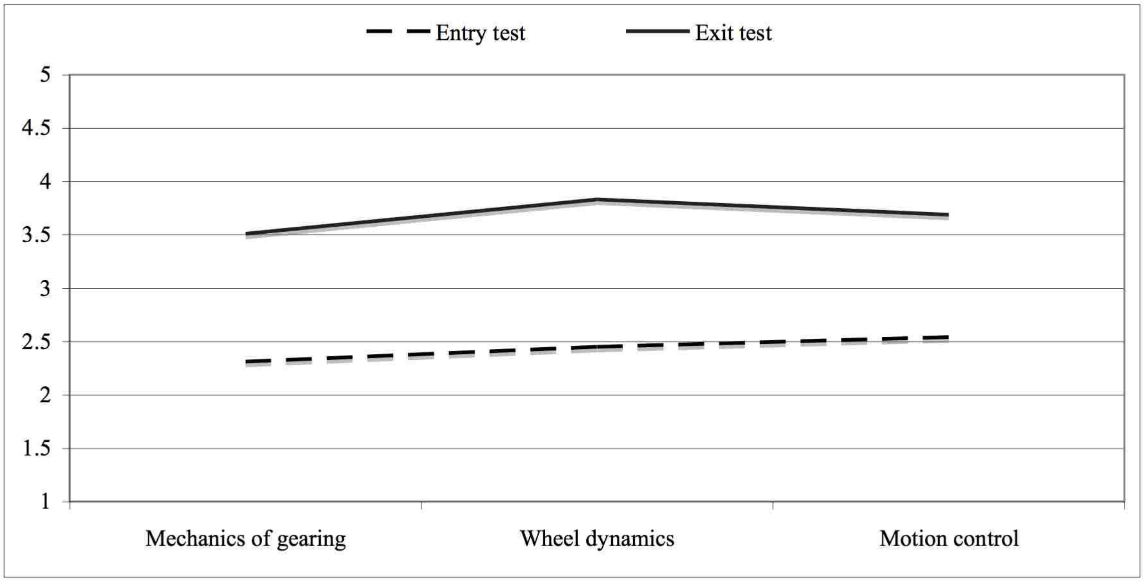


Figure 6.1. Comparison of Entry and Exit Test Mean Values

This research was conducted on a small group population. However, a within-group analysis revealed that the means of score for the three question groups were not significantly different both for pre-treatment ($F(3,53) = .20$, $p = .89$) and post-treatment ($F(3,53) = .31$, $p = .82$).

Because within group analysis revealed no significant differences between students' answers to the three groups of survey questions (gearing, dynamics and motion control) these questions were grouped and analyzed as one group for pre-training and respectively one post-training conditions. This way the population was to an equivalent population of N=53 students answering one test question, that was studied for between-subject effects. Table 6.1 summarizes these effects.

Table 6.1. Between-subjects Effects

Source	F	Sig.	Partial Eta Squared	Observed Power (alpha = 0.5)
Corrected Model	10.82	0.001	0.93	0.903

The overall mean score increase between the two tests (entry and exit) was 1.23, a 24.61% increase on the Likert 5-point evaluation scale. Individual topic mean statistics are shown in Table 6.2.

Table 6.2. Mean Scores for Extrapolated Data

Mean Score (1-5)	Entry test	Exit test	Percentage Increase
Mechanics of gearing	2.31	3.45	49.35%
Wheel dynamics	2.44	3.83	56.97%
Motion control	2.54	3.69	45.28%

6.1. OVERALL LEARNING IMPACT – QUALITATIVE ANALYSIS

The level of the students' skills as compared by the entry-test and exit-test scores showed a significant increase. The average mean score change between the beginning of training and the end of training was a 50.5% increase. This increase in performance can be given context by looking at the qualitative answers that were coded for each test. Table 6.3 summaries responses from students' pre to post-training that show the gain in the quality of answers due to the training. The second set of responses illustrates high score change between the student's entry and exit responses.

Table 6.3. Sample Qualitative of Student Gain from Pre to Post-training

Test	Question	Score Code	Qualitative Response
Entry	What is a control system? Give an example if possible.	1	No Answer.
Exit		5	"It's a controller that gives commands to a device or in our case a robot. It would be like a remote control for a T.V."
Entry	Explain how wheel rotations can be used to determine how far a robot has traveled.	3	"Every wheel rotation will be almost exactly the same as the last one. You can use this method to get close to where you are going but it isn't exact."
Exit		5	"If you know that one rotation of the wheel is equal to three inches, then you simple add up each rotation and multiply that by rotations and you have how far you traveled in inches."

Table 6.4 shows sample students' answers for post-training questions to exemplify the range of individual impact of the training even in a small group as this one.

Table 6.4. Sample Qualitative of Student Differences at Post-training

Student	Question	Score Code	Qualitative Response
#3	What is a ramp function?	3	"A function that allows speed to rise gradually rather than just off then on at full speed."
#5		5	"A ramp function allows to robot to gradually increase speed instead of going from say 0 to 100…the function would have the robot increase it's speed by like 10 units every 2 seconds or something. "
#6	What is a blob?	3	"A mass of color."
#1		5	"A collection of pixels in the same color range."

Besides the clear upward trend in the score change, student confidence levels were noted to increase as seen through the declining number of questions the students skipped. The number of non-answers per group on the exit test was less by 3.67 on average. Figure 6.2 summaries the number of non-answers.

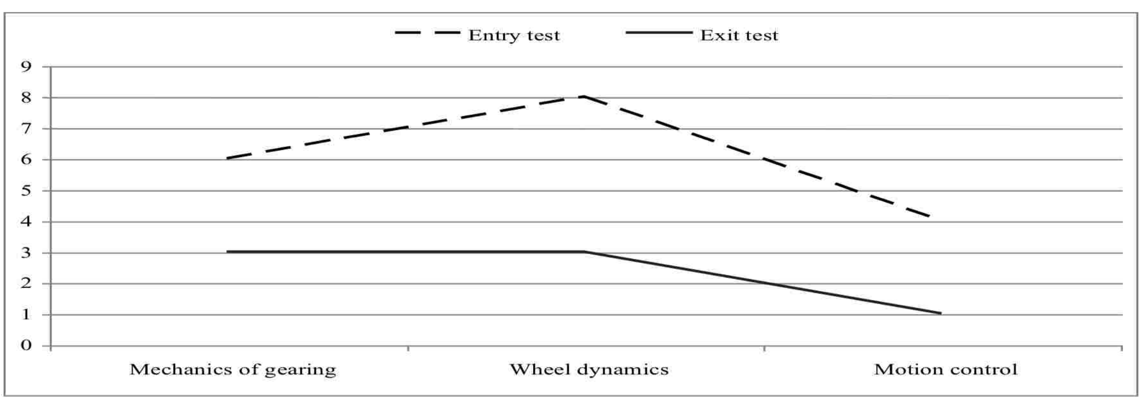


Figure 6.2. Comparison of Non-answer Count

6.2. ANALYSIS OF LEARNING THROUGHOUT EACH MAJOR TRAINING MODULE

The most commonly reported rating for all training modules combined was ‘much improved’. These ratings were then evaluated to determine the perceived effects of the individual components of each training module. The students reported that the verbal and written components of the training -- specifically the tutorial, restatement and review components of each training module – were ‘more helpful.’ The assessment activities were most commonly rated as ‘helpful.’

The instructor performed an estimation of performance of each student immediately following the conclusion of each training module. The observation-scoring rubric (see Section 5.3.2) was used to evaluate performance in each training module in the following categories: nomenclature, application of concept, activity performance, student improvement, student understanding, tutorial component, and assessment component. All components of performance estimation received an evaluation score of 3.5 or greater out of 5 with an overall mean score of 3.96. Figure 6.3 shows the mean values for each category averaged over all training modules.

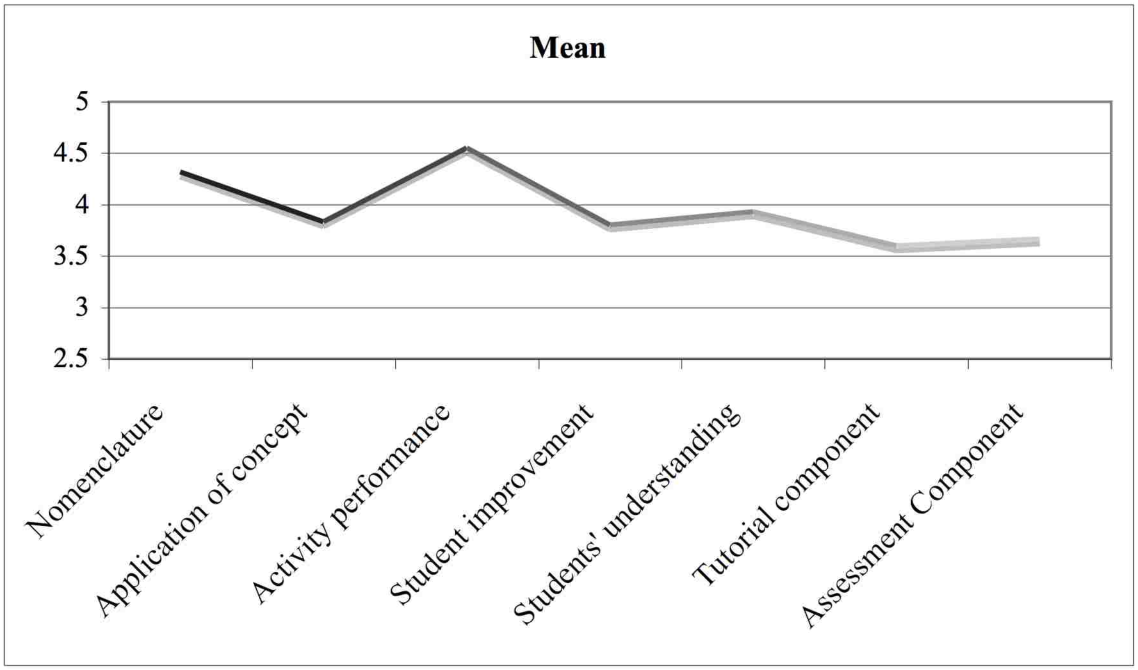


Figure 6.3. Instructor Estimated Performance

6.3. SUCCESS OF LEARNING

An important part of the training was to enable students to apply new skills and abilities to hands-on tasks. The results were evaluated based on the students' perceptions of the benefit of the hands-on assessment. The students were asked to evaluate the usefulness of the training for improving their understanding of the application of concepts to hands-on assessment tasks. Most students reported that the assessment was 'very helpful.'

Training assessment exercises were very successful. The assessment portion of the training modules elicited the most interest and excitement. Students repeatedly requested feedback on their performance and asked about other methods of accomplishing tasks using concepts not covered in the tutorials. Students also sought a better understanding the internal functions of hardware and the parameters of the systems used in the assessments. For example, some asked how the camera system finds pixel blobs in input images before post-processing analysis, or how accurate was the wheel rotation sensor. A third category of questions concerned how to transfer knowledge from the training to similar hardware systems and applications. The instructor observed that when the assessment was followed by a tutorial on the next training module, and when new concepts were linked to concepts previously introduced, student interest remained high from one module to another.

6.4. STUDENT PREPARATION FOR ROBOTICS COMPETITION

The Botball robotics competition gave some direction to the efforts of the students, and verbal reminders of the competition increased student interest. Most students rated their ability to apply the skills they had learned in training as ‘above average’ or ‘excellent,’ only one student indicating a rating of ‘average’ for one module. Both the mechanics of gearing and motion control modules were rated ‘excellent.’ The dynamics of wheeled vehicles module was rated as ‘above average.’ Student questions pertaining the use of a concept or seeking deeper understanding of a concept were directed related to tasks integral to the competition. These questions showed a valuable effort on the part of students to use the training material for effectively and learn from the researcher. Questions included the following:

- ‘What other opportunities are there in the Botball competition to use the concepts used in the hands-on activities?’
- ‘Could our robot perform better with this controller and how?’
- ‘We tried to do that last year but couldn’t get it to work…how can we use it this year?’

Their second year in attendance, the group performed well in using the training and practice they had received through this study’s training modules and won the double elimination tournament and finished third overall. The instructor observed proficient use and application of problem solving and robotic systems design skills.

The instructor performed a survey of each student following the conclusion of the Botball competition. The survey (see APPENDIX A.8) was used to evaluate students’ perception of the impact of the training on their performance in the competition. Students rated the group’s performance in the Botball competition as above average or excellent. Personal attitude toward science and mathematics was perceived to increase as well as skills needed for the Botball competition. The instructor’s training was reported to increase perceived preparation as well. Table 6.5 contains sample student responses of advice from the instructor that they found helpful for preparing them for the competition.

Table 6.5. Sample Qualitative of Instructor Advice the Students Found Valuable

Student	Question	Qualitative Response
#1	What from the advice the instructor gave you during the short training at S&T was helpful for your preparation for the Botball Competition? Please explain why.	"The presentation about ramp functions was very helpful. We found ramp functions to make a big difference in reliability."
#4		"The explanation about the gears and stuff helped me understand why you need so many gears on the robot."
#5		"Plan ahead. Because it was very necessary. "

The success of robotics training appears to be independent of the student interest in a STEM career. Students all noted as 'above average" or 'excellent' their ability to apply concepts introduced in training modules to the Botball competition, regardless of their interest in a STEM career. Even students who reported no interest in a STEM career indicated confidence in their ability to apply the training concepts. All students who reported previous exposure to robotics rated their confidence in doing robotics in the future as 'above average.' Students who had not been exposed previously reported 'low' confidence but reported the training as having improved their preparation for the competition at hand.

7. CONCLUSION

The findings of this study confirm that educational robotics outreach programs for high school students improve their ability to apply STEM material. Robotics provides a platform for the application of STEM topics and therefore increases interest in STEM careers. Also, strategies for teaching advanced robotics concepts in high school training programs can be successfully employed to instruct the students in the theory and practical application of STEM concepts with improvement seen to result from this mini training program. The students demonstrated this improvement in the group's performance in competition abilities and winning the double elimination tournament at the regional Botball competition. The instructor saw improvement in ability to precisely use and apply the mathematics and science knowledge to robotic activities.

The teaching strategies developed for this research revealed the following about the use of robotics to teach high school students STEM concepts and their application. First, the use of robotics provides sufficient incentive for the students to study STEM concepts. A clear objective, here the Botball robotics competition, gives direction to student training and provides a metric for evaluation of student performance. Students quickly absorb the concepts and recognize opportunities to apply them. Second, a physical demonstration of concepts or an assignment that introduces specific considerations necessary is helpful to students as they construct and program the application. Finally, student interest in all aspects of the training and their recognition of the importance of concepts for Botball depends on demonstrations or examples. Students were less interested in STEM concepts when they did not see any specific application for them. These findings demonstrate the direct relationship between student perception of the application of robotics to the Botball competition and the instructor's goal of improving their interest in and understanding of STEM topic through robotics.

This study demonstrated the successful adaptation of the researcher's masters of science engineering degree robotics knowledge to coursework, activities, and exercises suitable for teaching high school students. This case study functioned as a first try to analyze the effectiveness of forming a co-op between Missouri S&T and local high school educators to provide after school robotics education to supplement and improve students' science and mathematics competencies. It is believed that the use of graduate engineering mentors paired with high school students working on the Botball competition will improve student confidence and interest in STEM careers as was seen in this study. Teaching science classes an expanded robotics curriculum based on the learning material prepared for this study is expected to scale the results of this study and likewise show significant increases in students' mastery of the concepts and ability to apply them to the Botball competition.

APPENDIX

A.1. Main Objectives of the Botball Competition

The following paragraph details the objectives students involved in a Botball competition are intended to be able to demonstrate. The list was compiled by the researcher. (http://www.botball.org/about -- Compiled 09/06/2010)

General objectives

The student will be able to:

- Apply system dynamics to optimize robot control in programming implementation (concepts required for completion: math and mechanics statics/dynamics).
- Demonstrate knowledge of navigation techniques for object avoidance and robot path planning (concepts required for completion: path planning and robot localization).
- Program the microcontroller to use vision system output to control robot localization (concepts required for completion: programming, vision algorithms, and motion control).

Detailed Objectives

The following list enumerates topic headings for each of the general objectives. The detailed objectives are concepts that the researcher viewed as beneficial to the students to perform well in the Botball competition that are organized under their appropriate general objective.

- Math and Mechanical Statics/Dynamics
  - Gearing concepts
  - Lever concepts
  - Wheel dynamics concepts
- Path planning and robot localization
  - Wall following algorithms
  - Line following algorithms
  - Obstacle avoidance algorithms
- Directional/positional accuracy calculations
  - Proportional servo/wheel control
- Programming, vision algorithms, and motion control
  - Conditional programming techniques
  - Algorithm programming techniques
  - Position control through blob recognition
- Application of vision system data to navigation algorithms

Botball Competition

The following list contains collected descriptions of the Botball competition from the organizers of the Botball competition and my personal description. Together, these definitions should give the reader a more complete view of the function and design of the competition.

- "Team-oriented robotics competition based on national science education standards" (http://www.botball.org/about).
- "By designing, building, programming, and documenting robots, students use science, engineering, technology, math, and writing skills in a hands-on project that reinforces their learning" (http://www.botball.org/about).
- The Botball competition includes a series of gathering and collecting objects robot objectives within two minutes competition time limit.
- To compete in the Botball competition, students must build and program a robot to maneuver on the game board without the need for remote control using an interactive C programming language.

A.2. Rolla Regional Robotics Team Objectives for 2010

This presents the main objectives for the Rolla Regional Robotics Team for the 2010 competition. The objectives were gathered from interviews of an instructor and a member of the 2010 robotics team. The objectives are presented chronologically (compiled by the researcher on 09/02/2010).

The student will have to:

- Use problem solving/creative design to design a robot.
- Integrate robotic sensors, specifically the Botball kit to form a working robot that can complete the assigned task in a prescribed time period.
- Program in the C programming language the provided microcontroller (XBC) to complete the assigned competition tasks.

A.3. INTERVIEWS

A.3.1. 09/02/2010 – Adam Nisbett – Rolla Regional Robotics Team Instructor

Interview conducted by the researcher. The question the instructor was to identify was the objectives of the Rolla Regional Robotics Team in terms of competing in the yearly Botball competition. All topic headings for the objectives summarize the responses of the interviewee.

<u>Problem Solving Objectives</u>

- Find a solution to a given problem.
- Prioritize competition goals and decide how to use the two robots to accomplish those goals.
- Use creativity to complete the problem as fast as possible without sacrificing accuracy.

Robot Objectives

- Use sensors to improve system reliability for better understanding of surroundings.
- Learn coding techniques with programming for checks and balances so that if the robot cannot accomplish a local goal, it can still complete the higher-level goals.

Mathematics and Programming Objectives

- Improve understanding of programming.
- Explain the function of mathematics in robotics.

Future Objectives

- Use a machine-vision system for superior location data over the basic sensor output data.
- Use more mathematics in the design and implementation of systems.

A.3.2. 09/13/2010 – Adam Nisbett – Rolla Regional Robotics Team Instructor

Interview conducted by the researcher. The question asked what topics were covered in training sessions to prepare the Rolla Regional Robotics Team for the 2010 Botball Competition. All topic headings summarize the responses of the interviewee.

Programming

- Loops
- If-Then statements
- Variable assignment

Functions

- Hard Location (wheel rotations/touch sensors) positioning
- Introduction to machine vision (system not successfully implemented)

A.3.3. 09/05/2010 – Anonymous Rolla Regional Robotics Team Member

Interview conducted by the researcher. The question asked the interviewee to identify the objectives of the Rolla Regional Robotics Team for the Botball competition. All topic headings summarize the responses of the interviewee.

- Score the most points in the Botball competition.
- Learn design methods and engineering design process.
- Learn autonomous robot design (specifically, how to program an autonomous robot).

A.4. COLLEGE ROBOTICS CLASS CONTENT FOR GENERATING LIST OF POSSIBLE TRAINING TOPICS

The content and purpose of a college-level general robotics class provided a basis for the selection of topics. The class was offered by the Computer Science Department at Missouri University of Science and Technology and offered to computer science, computer engineering, and electrical engineering majors.

Course Title: "Introduction to Robotic Manipulations"

(http://cs.mst.edu/documents/sp2011_syllibus/CS_345-Wunsch.pdf compiled 09/06/2010)

Class Objectives

- Gain proficiency in system integration.
- Improve real-world problem solving skills.
- Learn robotic architectures, sensors, navigation, and simulation.

Topics Covered

- Introduction, Programming Robots, Player/Stage User Environment

- Obstacle Avoidance Overview
- State Machines, Simple Sensing
- Wheeled Kinematics
- Path Planning
- Arm Kinematics
- 3D (UAV, UUV) Kinematics
- Machine Vision
- Image Processing
- Programming the LabRat Practical Robotics System
- Advanced Obstacle Avoidance, Advanced Path Planning
- Swarm Intelligence
- Mechatronics
- Machine Learning

A.5. TRAINING DOCUMENTS

A.5.1 Gearing Training Module

Gearing Overview Worksheet

Intro: The purpose of the gearing overview is to explore how gears work and what they can be used for in robotics. It is not expected for you to master the material covered in this learning module the first time. Try to dig as deep as you can into the material and ask questions your team members and other facilitators as well. This worksheet will help you understand and apply the material about gearing.

Tutorial Link: Gear Tutorial

Instructions:

1. Read as a group the *Gear Tutorial* and watch both videos at the end of the tutorial

2. Re-watch the gear video chosen at the beginning of this meeting by the random drawing and think about some of the following questions to aid in processing the video.

a. What types of gears are used?

b. Did the speed increase or decrease through the gearing?

c. Why do the gears turn different directions?

d. What type of devices would contain this type of gear assembly?

e. How can this type of gear assembly be used in the Botball competition?

f. What have I learned about from this video that I can explain to the other team[s]?

3. Present what you have learned about the gearing video you just watched to the other groups.

4. Complete the final gearing assignment to learn how to practically use gears on robots!

Lesson Recap: Gear Recap

Gearing Assignment Worksheet

Procedure:

Build a simple robot that can be programmed to go forwards and carry a load. The robot does not need to be able to turn left or right. The robot should be timed to travel in a straight line for 3 feet with two loads. Run one experiment with no load and a 1:1 gear ratio from the motor to the wheels, the second with no load and a high gear ratio of 4:1, the third with a 1 lb load and a 1:1 gear ratio, and the four run with a 1lb load and a high gear ratio of 4:1. Gear Ratio = Large gear diameter/Small gear diameter

Example: Robot 1 with no load uses a motor that rotates at 10 revolutions a minute. The motor shaft has a diameter of 10 mm gear on it, and the gear connected to the wheel is 30 mm. The gear ratio would be 3:1, and the resulting velocity would be 30 revolutions a minute.

Student Activity:

Write a program that makes the robot go forward three feet and then stop. Run each program, record the time required for the robot to cover the three feet and then compare the time trials. (Return the robot to the starting position after each run.) After running the program four times, answer the questions at the bottom of the worksheet.

Gearing

Group #_______ Start Time: __________ End Time: ___________

How many revolutions did the motor complete in the 3ft test?

Revolutions:

#1

#2

#3

#4

Record time required for robot to reach end of run.

Time required:

#1

#2

#3

#4

1.) If it takes ___ revolutions to travel 3 ft, how fast was the robot traveling

(___ rev/ ___ time)?

#1

#2

#3

#4

2. a.) Compare the two runs with no load on the robot, how many times faster was the run with the high gear ratio (#1 time/#2 time)?

b.) Compare the two runs with no load on the robot, how many times faster was the run with the high gear ratio (#3 time/#4 time)?

Hardware Training : Gearing Rubric

Instructor Name: Matthew **Strautmann**

Group Name: ______________________________

Purpose: To allow the instructor to ascertain the level of group knowledge of the topic at hand.

Given to and when : Performed with Hardware group before starting Gearing Training and again at end of training to determine new level of knowledge

Rubric format: Instructor verbal questioning of group members with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the participant seeing the rubric score.

CATEGORY	1	2	3	4	5
Identify different gear types such as spur, rack and pinion, worm, etc?	No Clue		Got lucky!		Identify Spur
	No Clue		Got lucky!		Identify Rack and Pinion
	No Clue		Got lucky!		Identify Worm
Explain how gears work	No Knowledge		Know it involves to gears touching		Understand Meshing
	No Knowledge		Know they are the point around the circle		Understand Teeth
Explain what a gear ratio is?	No Knowledge		Know formula but can't explain purpose or variables		Understand Formula
Explain the difference between force and speed?	Can't define either		Can define one		Can define both
	Can't determine either				Can determine both
Apply gear ratio theory to Botball?	Don't see use for gearing		Understand what a gear is but can't give application for the concept		Used it already, or would have been useful last year
Apply gear ratio theory in the future?	Not helpful at all		Understand it, but can't apply it		Understand it and can apply it

Purpose: To allow the instructor to ascertain the level of completion and understanding of assessment portion of the topic at hand.

Given to and when : Performed with Hardware group after finishing Gearing Assessment Worksheet

Rubric format: Instructor verbal questioning of group members and inspection of group worksheet with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the participant seeing the rubric score.

Understand gear assignment?	Did not understand		Needed instructor input to understand assignment in addition to initial instruction and lecture		Understood based on gear lecture
Complete gear assignment?	Ran out of time		Partial completed or completed by not correctly		Finished with good accuracy
1.) Percentage off wheel speed for 3 ft demo assignment	High Error		Medium Error		Low Error
2.) Percentage off 4:1 ratio question	High Error		Medium Error		Low Error

Purpose: To allow the instructor to ascertain the final outcome of the current training module!

Given to and when : Performed with Hardware group after finishing Gearing Training and Gearing Assessment Worksheet

Rubric format: Instructor verbal questioning of group members with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the participant seeing the rubric score.

Compare participant knowledge before and after training module	No improvement		Improved in some areas		Much improved especially in application of concepts
Function of training in new knowledge	No connection		Understood a few things from training		Most important factor in learning
Function of assessment in new knowledge	No connection		Understood a few things from assessment		Most important factor in learning
Perceived participant benefit for Botball competition	No benefit		Some		Very helpful!

Date Created: Jan 12, 2011 10:59 am (UTC)

Figure A.5.1.1. Gearing Rubric Document

Gearing Tutorial

(www.gotbots.org, edited and content re-arranged by researcher, 02/20/2011)

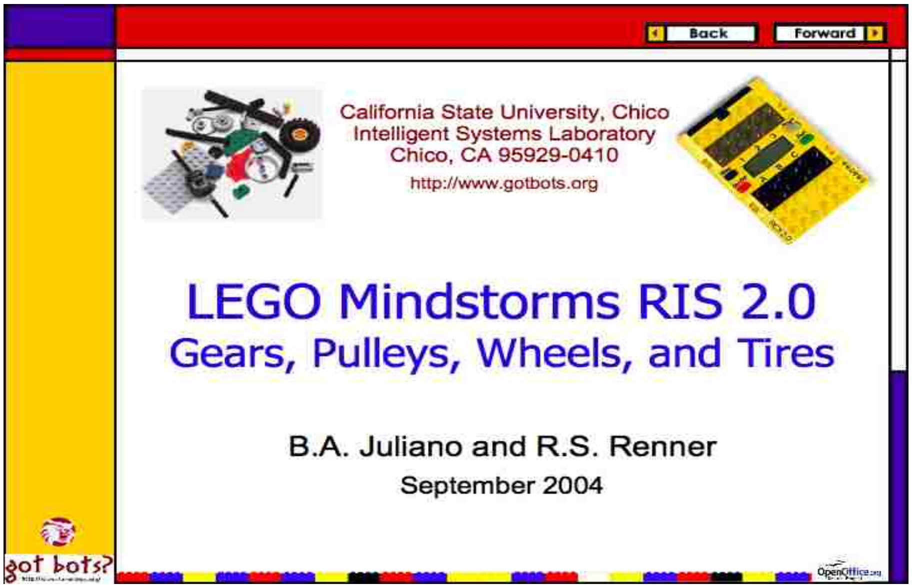


Figure A.5.1.2: Gearing Tutorial Page 1

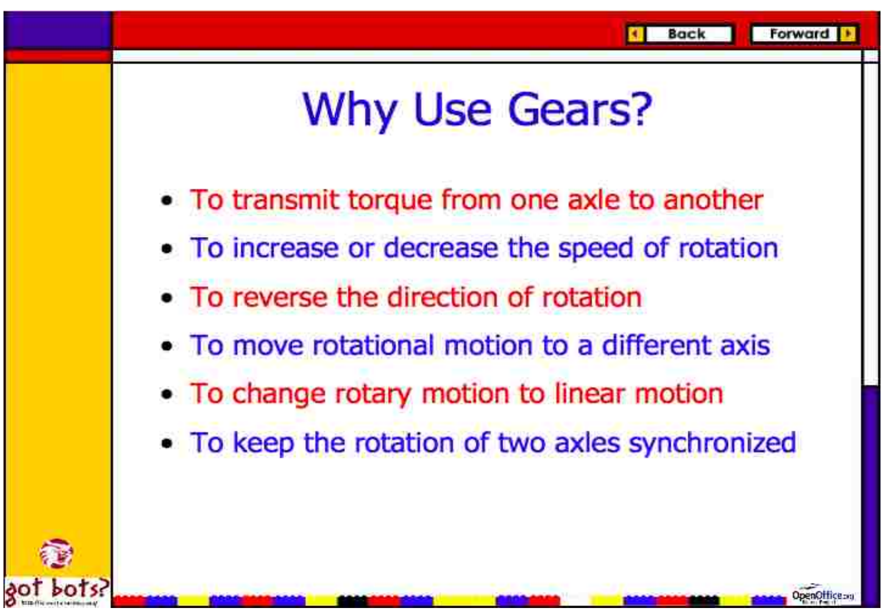


Figure A.5.1.3: Gearing Tutorial Page 2

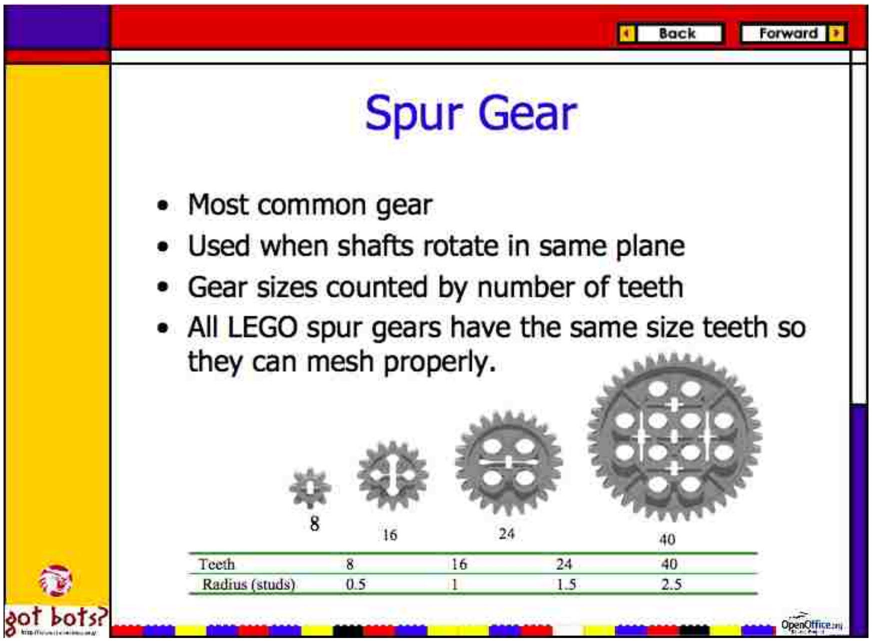


Figure A.5.1.4: Gearing Tutorial Page 3

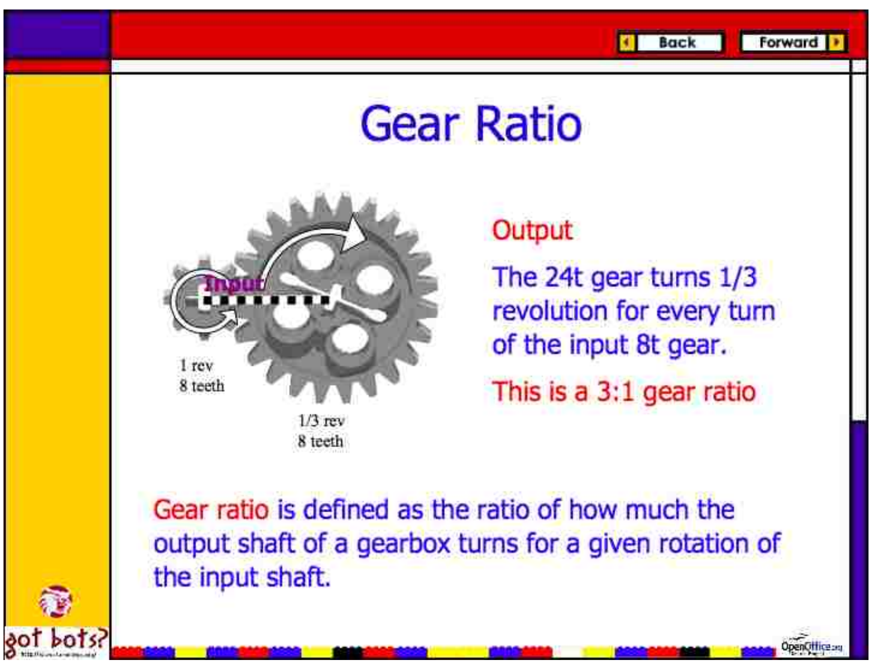


Figure A.5.1.5: Gearing Tutorial Page 4

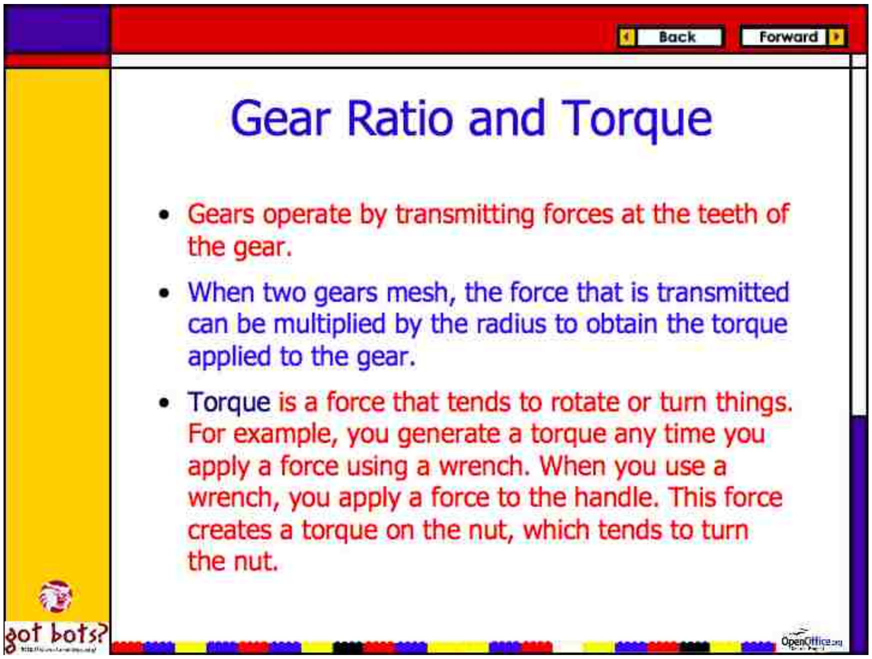


Figure A.5.1.6: Gearing Tutorial Page 5

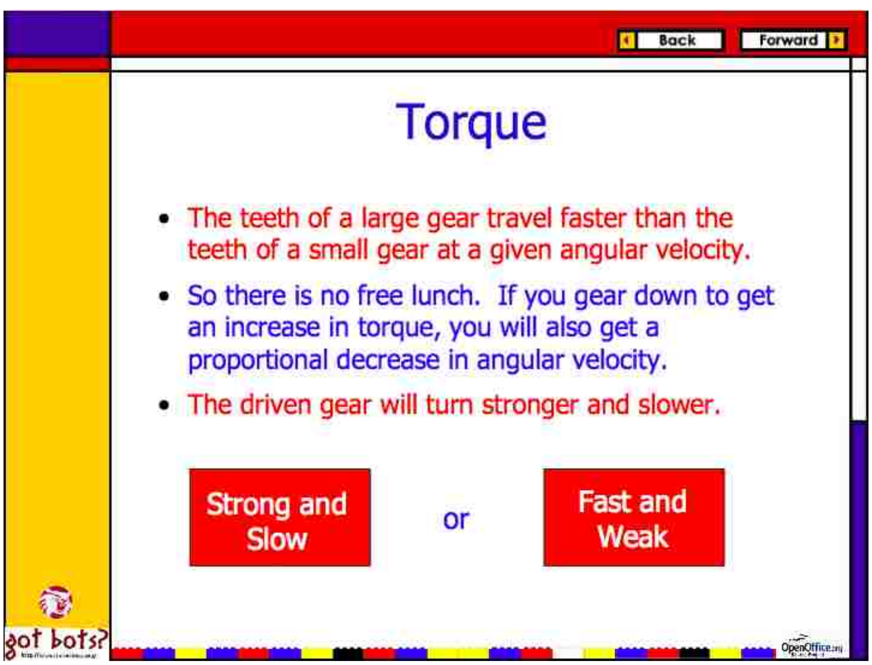


Figure A.5.1.7: Gearing Tutorial Page 6

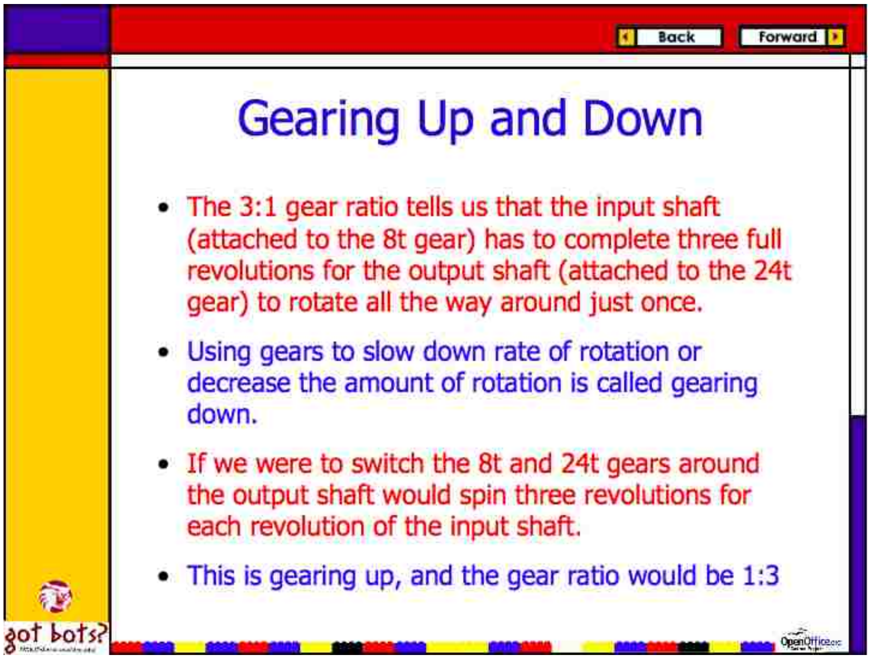


Figure A.5.1.8: Gearing Tutorial Page 7

Figure A.5.1.9: Gearing Tutorial Page 8

A.5.2. Dynamics of Wheeled Robots

Dynamics of Wheeled Robots Overview Worksheet

Intro:

The purpose of the wheel dynamics overview is to explore how a robot moves from point A to point B and what speed it travels when making the trip. It is not expected for you to master the material covered in this learning module the first time. The material in this tutorial will use terms that you will not have seen yet in your education. Learn as you can into the material and ask questions your team members and other facilitators as well. This worksheet will help you understand and apply the material about dynamics.

Tutorial Link: Wheel Dynamics

Instructions:

1. Review as a group the Wheel Dynamics Tutorial and experiment with the RMF Calculator. Alter some of the "Desired Robot Inputs" and see how this changes "Motor Rotation Speed" under the heading "RMF Results:"

2. Discuss as a group the following questions:

a. What factors can keep the robot from traveling the distance programmed in?

i. Friction?

ii. Wheel slip?

iii. Motor differences?

b. What is one reason the motors might not turn at the same speed?

c. Which will give you better accuracy at arriving at a precise distance?

i. A slowly increasing speed?

ii. Just turn on the motors. The tires will not slip?

d. How can the motors be better used in the Botball competition over last year?

e. What have I learned about from this tutorial that I can explain to the other team[s]?

3. Present what you have learned to the other groups.

4. Complete the final wheel dynamics assignment to learn how to practically use the wheel dynamics equations on robots!

Dynamics of Wheeled Robots Assignment Worksheet

Procedure:

Build a simple robot that can be programmed to drive forwards. The robot must have two motors and a free-spinning rear wheel. For the first part of this unit, write a program to command the robot to drive forwards. Tune the motor voltage value until the wheels turn at the same speed as seen by a robot that can follow a line without input. For the second part of this unit, write a program to make the robot travel 3ft, and set a yardstick underneath the robot and run the program 3 times. Lastly, write a program to turn the robot 90 degrees.

Student Activity:

Run first element until robot drives straight. Calculate wheel rotations needed to travel 3ft and then convert that number to ticks for program code. Run program 3 times. Write program to turn robot 90 degrees and test three times. After completing unit, answer the questions at the bottom of the worksheet.

Wheel Dynamics Group #_______ Start Time: __________ End Time: ___________

Part 1) Left Wheel Voltage: _________ Right Wheel Voltage: _________

Part 2) # wheel rotations to travel 3ft? _______

Part 3) Left Wheel Voltage ______ and # of rotations _________.

Right Wheel Voltage ______ and # of rotations _________.

1.) Why are the wheel voltages not the same in the straight-driving test?

2.) Why does one wheel need to complete more rotations then the other one when turning?

Hardware Training : Dynamics of Wheeled Robots Rubric

Instructor Name: Matthew **Strautmann**

Group Name: ______________________

Purpose: To allow the instructor to ascertain the level of group knowledge of the topic at hand.

Given to and when : Performed with Hardware group before starting Wheel Dynamics Training and again at end of training to determine new level of knowledge

Rubric format: Instructor verbal questioning of group members with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the participant seeing the rubric score.

CATEGORY	1	2	3	4	5
Explain how wheel dynamics work?	What's a wheel again?				I can make the robot drive straight!
Explain how motor voltage control works?	No Knowledge		Know used it in the past but can't explain purpose or variables		Understand concept
Explain the difference between torque and speed?	Can't define either		Can define one		Can define both
	Can't differentiate either				Can differentiate both
Apply wheel dynamics ratio theory to Botball?	Don't see use for wheel dynamics		Understand importance but can't give application for the concept		Used it already, or would have been useful last year
Apply wheel dynamics ratio theory in the future?	Not helpful at all		Understand it, but can't apply it		Understand it and can apply it

Purpose: To allow the instructor to ascertain the level of completion and understanding of assessment portion of the topic at hand.

Given to and when : Performed with Hardware group after finishing Wheel Dynamics Assessment Worksheet

Rubric format: Instructor verbal questioning of group members and inspection of group worksheet with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the part

CATEGORY	1	2	3	4	5
Understand Wheel Dynamics assignment?	Did not understand		Needed instructor input to understand assignment in addition to initial instruction and lecture		Understood based on Wheel Dynamics lecture
Complete Wheel Dynamics assignment?	Ran out of time		Partial completed or completed by not correctly		Finished with good accuracy
1.) Wheel voltage difference for driving straight	No clue		Needed instructor input to understand assignment in addition to initial instruction and lecture		Understand and can explain basis
2.) Wheel rotation difference between left and right wheel for turning	No clue		Needed instructor input to understand assignment in addition to initial instruction and lecture		Understand and can explain basis

Purpose: To allow the instructor to ascertain the final outcome of the current training module!

Given to and when : Performed with Hardware group after finishing Wheel Dynamics Training and Wheel Dynamics Assessment Worksheet

Rubric format: Instructor verbal questioning of group members with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the participant seeing the rubric score.

CATEGORY	1	2	3	4	5
Compare participant knowledge before and after training module	No improvement		Improved in some areas		Much improved especially in application of concepts
Function of training in new knowledge	No connection		Understood a few things from training		Most important factor in learning
Function of assessment in new knowledge	No connection		Understood a few things from assessment		Most important factor in learning
Perceived participant benefit for Botball competition	No benefit		Some		Very helpful!

Date Created: Jan 12, 2011 10:59 pm (UTC)

Figure A.5.2.1. Dynamics of Wheeled Robots Rubric

Dynamics of Wheeled Robots Tutorial

(http://www.societyofrobots.com/mechanics_dynamics.shtml)

Robot Dynamics

Introduction to Mechanical Engineering Theory, Dynamics

While statics is the study of structures at a fixed point in time, dynamics is the study of structures over a period of time. Basically statics studies things that dont move, while dynamics studies things that do. Statics is concerned with moments, forces, stresses, torque, pressure, etc. Dynamics is concerned with displacement, velocity, acceleration, momentum, etc. If you want to calculate and/or optimize forces generated or required for a moving robot, this tutorial has the basics that you will need to understand. It is highly recommended you read the statics tutorial first as this tutorial will build off of it.

Displacement and Velocity

We all know what velocity is, but how do you design a robot to go at a defined velocity? Of course you can put a really fast motor on your robot and hope that it will go fast enough. But if you can calculate it you can design it to go your required speed without doubt, and leave the rest of the motor force for torque.

So how to do this? For an example, suppose you have a wheeled robot that you want to run over old people with. You know from experiments that old people can run at 3 feet per second. So what motor rpm do you need, and what diameter should your wheels be, so they cant get away or hide their medicine?

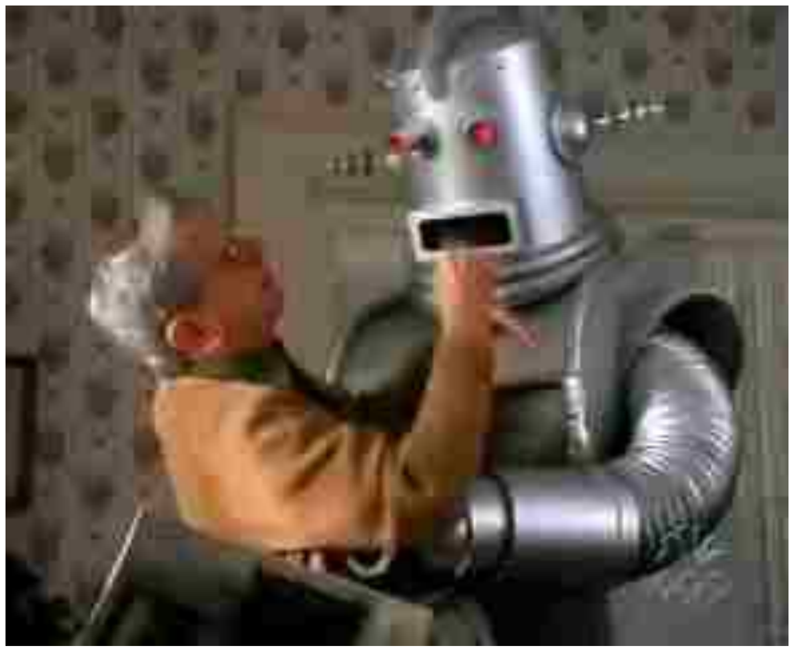


Figure A.5.2.2: Robot Attacking Person

Conceptually, every time your wheel rotates an entire revolution, your robot travels the distance equal to the circumference of the wheel. So multiply the circumference by the number of rotations per minute, and you then get the distance your robot travels in a minute.

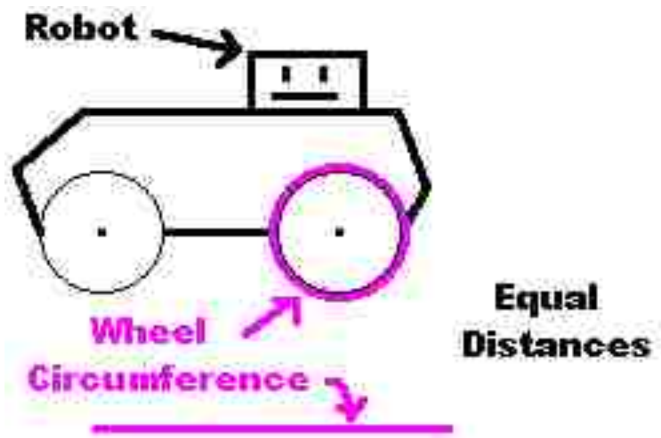


Figure A.5.2.3. Robot Wheel Circumference Illustration

Velocity = circumference * rpm (1)

Velocity = diameter * pi * rpm OR Velocity = 2 * radius * pi * rpm (2)

For example, if your motor has a rotation speed (under load) of 100rpm (determined by looking up the motor part number online) and you want to travel at 3 feet per second, calculate:

3 ft/s = diameter * pi * 100rpm (3)

3 ft/s = diameter * pi * 1.67rps (rotations per second) (4)

diameter = 3 ft/s / (3.14 * 1.67 rps) (5)

diameter = 0.57 ft, or 6.89" (6)

Robot Wheel Diameter vs Torque

You probably noticed that the larger the diameter of the wheel, or higher the rpm, the faster your robot will go. But this isn't entirely true in that there is another factor involved. If your robot requires more torque than it can give, it will go slower than you calculated. Heavier robots will go slower. Now what you need to do is compare the *motor torque*, your robot *acceleration*, and *wheel diameter*. These three attributes will have to be balanced to achieve proper torque.

Motor Torque and Force

High force is required to push other robots around, or to go up hills and rough terrain, or have high acceleration. As calculated with *statics*, just by knowing your wheel diameter and motor torque, you can determine the force your robot is capable of.

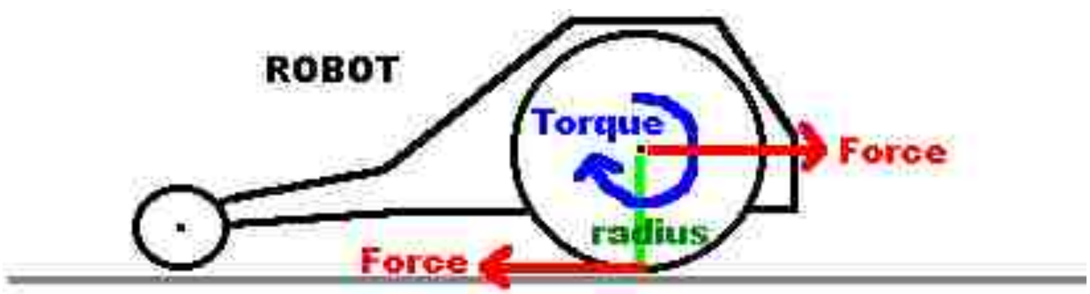


Figure A.5.2.4. Motor Torque and Force

Torque = Distance * Force (7)

Distance = Wheel Radius (8)

Force = Torque / Wheel Radius (9)

Acceleration

But you also want to be concerned with acceleration. For a typical robot on flat terrain, you probably want acceleration to be about half of your max velocity. So if your robot velocity is 3 ft/s, you want your acceleration to be around 1.5 ft/s^2. This means it would take 2 seconds (3 / 1.5 = 2) to reach maximum speed.

Remember that:

Force = Mass * Acceleration (10)

There is one other factor to consider when choosing acceleration. If your robot is going up inclines or through rough terrain, you will need a higher acceleration due to countering gravity. If say your robot was going straight up a wall, you would require an additional 9.81 m/s^2 (32 ft/s^2) acceleration to counteract. A typical 20 degree incline (as shown) would require 11 ft/s^2.

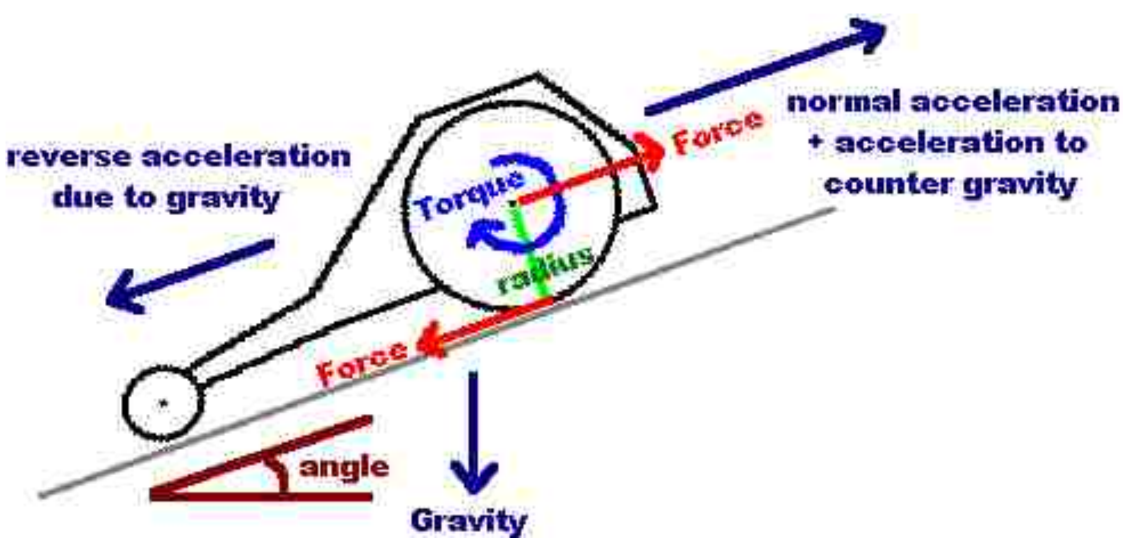


Figure A.5.2.5. Force on a Slope

How do you calculate how much additional acceleration you would need for a specific incline?

acceleration for inclines = 32 ft/s^2 * sin((angle_of_incline * pi) / 180) (11)

You must add this acceleration to what you already require for movement on flat terrain.

Note that motor acceleration and torque are not constants, and that motor acceleration will decrease as motor rotational velocity increases. As it's very dependent on the motor, this tutorial will gloss right over it for simplicity.

Robot Motor Factor

The robot motor factor (RMF) is something I made up. It is simply a way I devised to make your life simpler so you can do a quick calculation to optimize your robot. Basically I combined and simplified all the equations above into one big equation to help you choose the motor that best suits your robot.

*Torque * rps > = Mass * Acceleration * Velocity / (2 * pi)* (12)

RMF = Torque * rps (13)

1) To use this equation, look up a set of motors you think will work for your robot and write down the torque and rps (rotations per second) for each.

2) Then multiply the two numbers together for each. This will be your robot motor factor.

3) Next, estimate the weight of your robot. Basically add up the weight of all the parts.

4) Lastly, choose your desired velocity and acceleration.

5) Compare both sides of the equation

Example. Suppose you found three motors:

Motor A: 2 lb ft, 1rps => RMF = 2 lb ft rps

Motor B: 2.5 lb ft, 2rps => RMF = 5 lb ft rps

Motor C: 2 lb ft, 4rps => RMF = 8 lb ft rps

Now suppose you want a velocity of 3 ft/s, an acceleration of 2 ft/s^2, and you estimate your robot weight to be 5 lbs.

so RMF >= 5 lbs * 2 ft/s^2 * 3 ft/s / (2 * pi)

therefore RMF >= **4.77** lb * ft * rps

So this means you need a motor with an RMF greater or equal to 4.77. Looking at your list, Motor B and C both will work. However Motor C is probably overkill, so it's just a waste of money. Therefore you would use Motor B. Just note that if none of the motors would work, you would have to either reduce weight, or go slower, or find another motor.

note: if you convert rps to radians/sec, RMF can be measured in watts

Calculating Wheel Diameter

So now what robot wheel diameter should you use? Going back to an earlier equation, velocity = diameter * pi * rps (14)

OR

diameter = velocity / (pi * rps) (15)

3 ft/s / (pi * 2/s) = wheel diameter = .48 feet = 5.73" (16)

You are finished! You use motor B, with a wheel diameter of 5.73", and never again will your robot fail at plowing over the neighborhood cat.

Although the above equations are intended for robot wheels, they will also work for any other robot part. If you were say designing a robot arm, instead of using diameter use robot arm length. Then you can calculate how fast the arm will move with a certain weight being carried, for example.

Robot Motor Factor, Efficiency

The RMF you calculated is only for a 100% efficient system. But in reality this never happens. Gearing and friction and many other factors cause inefficiency. I won't go into how to calculate efficiency, but there are general rules that would get you really close. If you have external (not inside the motor) gearing, reduce your efficiency by ~15%. If you are using treads like on a tank robot, reduce by another ~30%. If your robot operates on rough high friction terrain, reduce another ~10%. For example, a tank robot on rough terrain would have an efficiency of (100% - 30%)*(100% - 10%) = 63% or 0.63.

The RMF equation, incorporating efficiency, is

Torque * rps > = Mass * Acceleration * Velocity * (1/efficiency) / (2 * pi) (17)

where efficiency is a percentage expressed as a decimal number (i.e. 80% = .8).

Momentum

Ever notice how heavier things are harder to push than lighter things? This is because of momentum. Knowing your robot's momentum is very important if you want high acceleration for your robot. If your robot is heavy, it will take forever for a weak motor to get it to go fast. How do you determine the momentum of your robot? Just *multiply the mass times the velocity*. Lower momentum is better for mobility and higher energy efficiency. Higher momentum is better for beating up other robots . . . and people.

Momentum = Mass * Velocity (18)

Figure A.5.2.6. Robots Attacking a Person

A.5.3. Blob Recognition

Blob Recognition Overview Worksheet

Intro:

The purpose of the blob recognition overview is to explore the functionality of the camera system with its blob recognition software and how it can be used to guide the robot through a course. Ask questions your team members and other facilitators as well. This worksheet will help you understand and apply the material about blob recognition.

Tutorial: Blob Recognition Methods

Code Link: NXTCam-v2 - Tutorial - Object Recognition and Line Following Robot

http://www.mindsensors.com/index.php?module=pagemaster&PAGE_user_op=view_page&PAGE_id=130, accessed 7/11/11.

Instructions:

1. Read through the Blob Recognition Methods overview.

2. Watch both videos and then re-watch your randomly assigned video demonstrating an aspect of Blob Recognition, thinking through the questions from

Video 1: http://www.youtube.com/watch?v=1x5NP_k_zEI&feature=player_embedded

Video 2: http://www.youtube.com/watch?v=x2od63eroPY&feature=player_embedded

4. Discuss as a group the following questions after you watch the blob recognition video.

a. What was the camera actually tracking?

b. What method of Blob Recognition from the tutorial do you think was used?

c. What would happen if the robot missed the colored paper and reached the end of the line?

d. What have we learned about from this video that we can explain to the other team[s] about how to utilize the camera system?

4. Present what you have learned about blob recognition to the other groups.

5. Read the Read-Me text file accompanying the code and watch the included video.

6. Following the included instructions in the Read-Me, run the program.

7. Complete the final blob recognition assignment about how to practically use camera systems on robots!

Notes: Videos taken from: http://www.societyofrobots.com/programming_computer_vision_tutorial_pt3.shtml

Blob Recognition Assignment Overview

Procedure:

Using black electrical tape, construct a path on a light colored or white surface. Build a robot with two forward drive wheels and a free rear wheel. Mount the camera to the top of the robot facing down.

Student Activity:

Use the blob detection software to center the robot on the blob. (Return the robot to the starting position after each run.) After running each program/robot configuration several times, discuss the results at the bottom of the worksheet.

Blob Recognition Group #_______ Start Time: __________ End Time: ___________

1.) What problems were found when implementing the vision system, line follower?

2.) What other uses are there for this vision system?

3.) Did your robot turn at the colored paper? YES NO

4.) Did it complete the course? YES NO

Software Training : Blob Recognition Rubric

Instructor Name: Matthew **Strudmann**

Group Name: ______________________

Purpose: To allow the instructor to ascertain the level of group knowledge of the topic at hand.

Given to and when: Performed with Software group before starting Blob Recognition Training and again at end of training to determine new level of knowledge

Rubric format: Instructor verbal questioning of group members with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the participant seeing the rubric score.

CATEGORY	1	2	3	4	5
Explain how blob recognition works?	No Knowledge		Know it involves the camera		Understand Blob Recognition software and how to explain with examples
Explain which way to turn to head toward or away from a blob?	No clue		How does this pertain to blobs..I can explain blobs though!		Explain Blob Recognition and application to Wheel Dynamics
Explain how blob recognition can be used to determine current position and proper drive direction?	Don't see use for Blob Recognition		Understand what Blob Recognition is but can't give application for the concept		Can explain application to current position and drive direction
Design a vision control system assembly?	What is a vision control system?		I can define a vision control system but not tell you how to create one		Can design a viable vision control system
Apply blob recognition to Botball?	Not helpful at all		Understand it, but can't apply it		Understand it and can apply it
Apply blob recognition theory in the future?	Not helpful at all		Understand it, but can't apply it		Understand it and can apply it

Purpose: To allow the instructor to ascertain the level of completion and understanding of assessment portion of the topic at hand.

Given to and when: Performed with Software group after finishing Blob Recognition Assessment Worksheet

Rubric format: Instructor verbal questioning of group members and inspection of group worksheet with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the part

Understand Blob Recognition assignment?	Did not understand		Needed instructor input to understand assignment in addition to initial instruction and lecture		Understood based on Blob Recognition lecture
Complete Blob Recognition assignment?	Ran out of time		Partial completed or completed but not correctly		Finished with good accuracy
1.) What problems were found when implementing the vision system /line follower?	No problems		A few recognized		Low Error
2.) What other uses are there for this vision system?	None		One practical use		Multiple practical uses
3.) Did your robot turn at the colored paper?	No		Sort of		Yes
4.) Did it complete the course?	No		Half		Yes

Purpose: To allow the instructor to ascertain the final outcome of the current training module!

Given to and when: Performed with Software group after finishing Blob Recognition Training and Blob Recognition Assessment Worksheet

Rubric format: Instructor verbal questioning of group members with results recorded on this rubric with one being "question poorly/not completely answered" and five being " question sufficiently answered" without the participant seeing the rubric score.

Compare participant knowledge before and after training module	No improvement		Improved in some areas		Much improved especially in application of concepts
Function of training in new knowledge	No connection		Understood a few things from training		Most important factor in learning
Function of assessment in new knowledge	No connection		Understood a few things from assessment		Most important factor in learning
Perceived participant benefit for Botball competition	No benefit		Some		Very helpful!

Figure A.5.3.1. Blob Recognition Rubric

Blob Recognition Tutorial

Definition of a Blob: a single, connected region in a color or grayscale image.

Middle Mass and Blob Detection

Blob detection is an algorithm used to determine if a group of connecting pixels are related to each other. This is useful for identifying separate objects in a scene, or counting the number of objects in a scene. Blob detection would be useful for counting people in an airport lobby, or fish passing by a camera. Middle mass would be useful for a baseball catching robot, or a line following robot.

To find a blob, you threshold the image by a specific color as shown below. The blue dot represents the middle mass, or the average location of all pixels of the selected color.

Figure A.5.3.2. Object Centroid

If there is only one blob in a scene, the middle mass is always located in the center of an object. But what if there were two or more blobs? This is where it fails, as the middle mass is no longer located on any object:

Figure A.5.3.3. Blob Recognition Rubric

To solve for this problem, your algorithm needs to label each blob as seperate entities. To do this, run this algorithm:

go through each pixel in the array:

if the pixel is a blob color, label it '1'

  otherwise label it 0

go to the next pixel

  if it is also a blob color

    and if it is adjacent to blob 1

label it '1'

else label it '2' (or more)

repeat until all pixels are done

What the algorithm does is labels each blob by a number, counting up for every new blob it encounters. Then to find middle mass, you can just find it for each individual blob.

In this below video, I ran a few algorithms in tandem. First, I removed all non-red objects. Next, I blurred the video a bit to make blobs more connected. Then, using blob detection, I only kept the blob that had the most pixels (the largest red object). This removed background objects such as the fire extinguisher. Lastly, I did center of mass to track the actual location of the object. I also ran a *population threshold* algorithm that made the object edges really sharp. It doesn't improve the algorithm in this case, but it does make it look nicer as a video.

(Note: video link included in Blob Recognition Worksheet.)

Tracking

By doing motion detection by calculating the motion of the middle mass, you can run more advanced algorithms such as tracking. By doing vector math, and knowing the pixel to distance ratio, one may calculate the displacement, velocity, and acceleration of a moving *blob*.

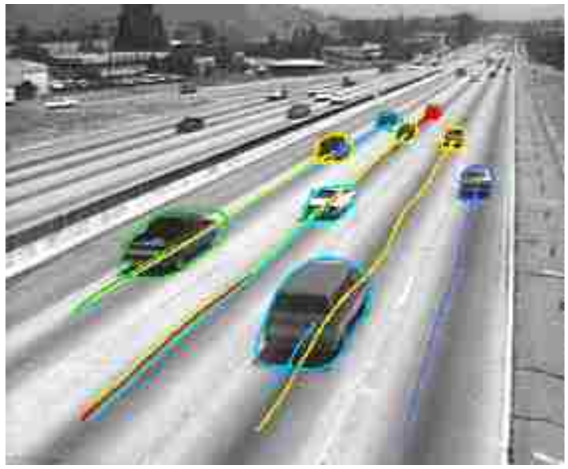


Figure A.5.3.4. Blob Tracking

Here is an example on how to calculate speed of a car:

calculate the middle mass in frame 1

wait X seconds

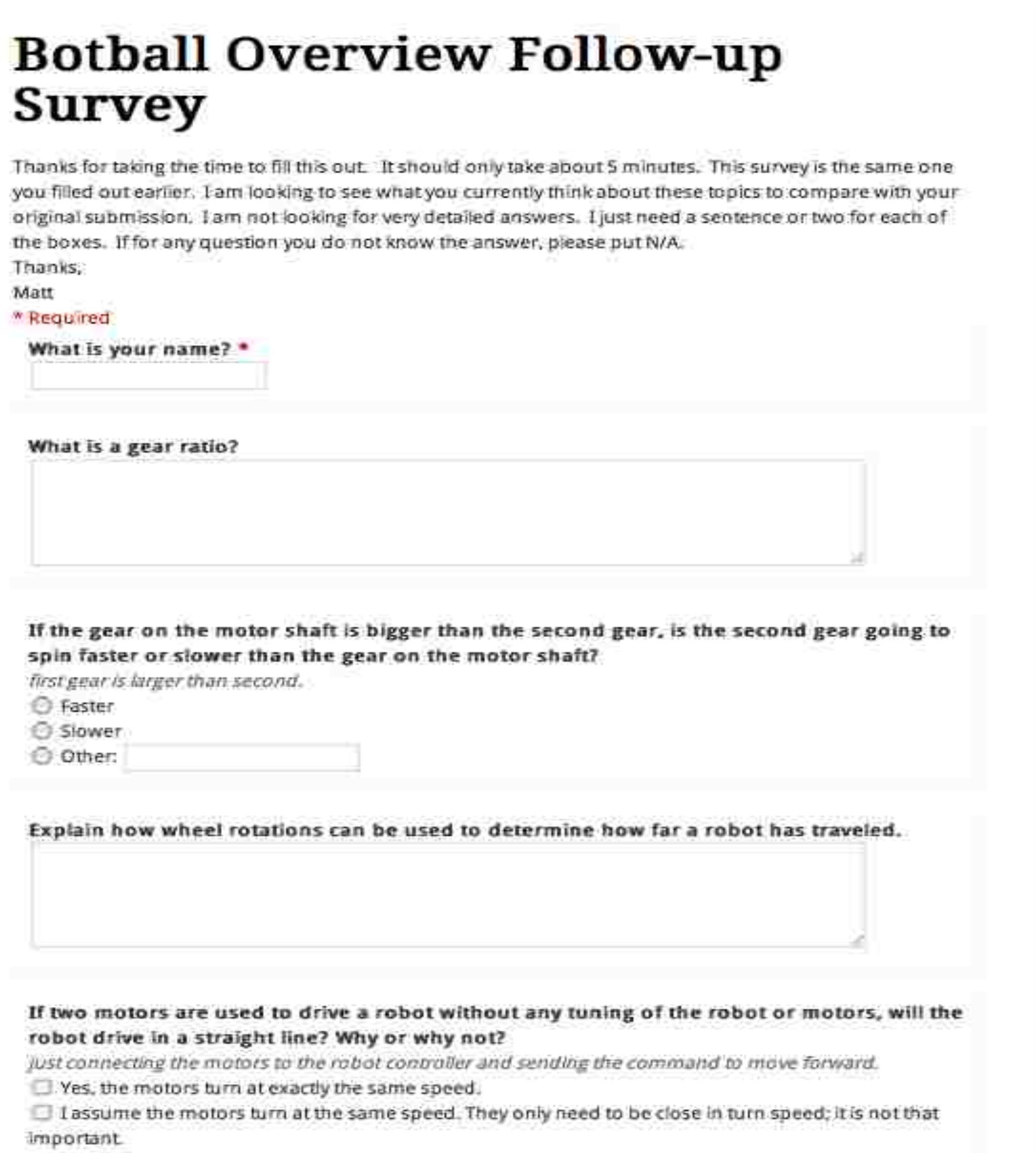
calculate the middle mass in frame 2

speed = (mm_frame_1 - mm_frame_2) * distance / per_pixel

Problems with tracking:

The major issue with this algorithm is *determining the distance to pixel ratio*. If your camera is at an angle to the horizon (not looking overhead and pointing straight down), or your camera experiences the *lens effect* (all cameras do, to some extent), then you need to write a separate algorithm that maps this ratio for a given pixel located at X and Y position.

A.6.3. Entry-Level Skills Assessment



Botball Overview Follow-up Survey

Thanks for taking the time to fill this out. It should only take about 5 minutes. This survey is the same one you filled out earlier. I am looking to see what you currently think about these topics to compare with your original submission. I am not looking for very detailed answers. I just need a sentence or two for each of the boxes. If for any question you do not know the answer, please put N/A.
Thanks,
Matt
* Required

What is your name? *

What is a gear ratio?

If the gear on the motor shaft is bigger than the second gear, is the second gear going to spin faster or slower than the gear on the motor shaft?
first gear is larger than second.
- Faster
- Slower
- Other:

Explain how wheel rotations can be used to determine how far a robot has traveled.

If two motors are used to drive a robot without any tuning of the robot or motors, will the robot drive in a straight line? Why or why not?
just connecting the motors to the robot controller and sending the command to move forward.
- Yes, the motors turn at exactly the same speed.
- I assume the motors turn at the same speed. They only need to be close in turn speed; it is not that important.

Figure A.6.3.1. Entry Level Skills Assessment Page 1

☐ No, all motors must be checked to make sure they turn at the same speed
☐ Other:

What is a control system? Give an example if possible.

What is a ramp function?

Explain how a robot can follow a line using only a light sensor to tell the robot if the space under the sensor is a line or not?

Assume the line is black, the background is white, and the line is to the right of the sensor.

What is a blob?

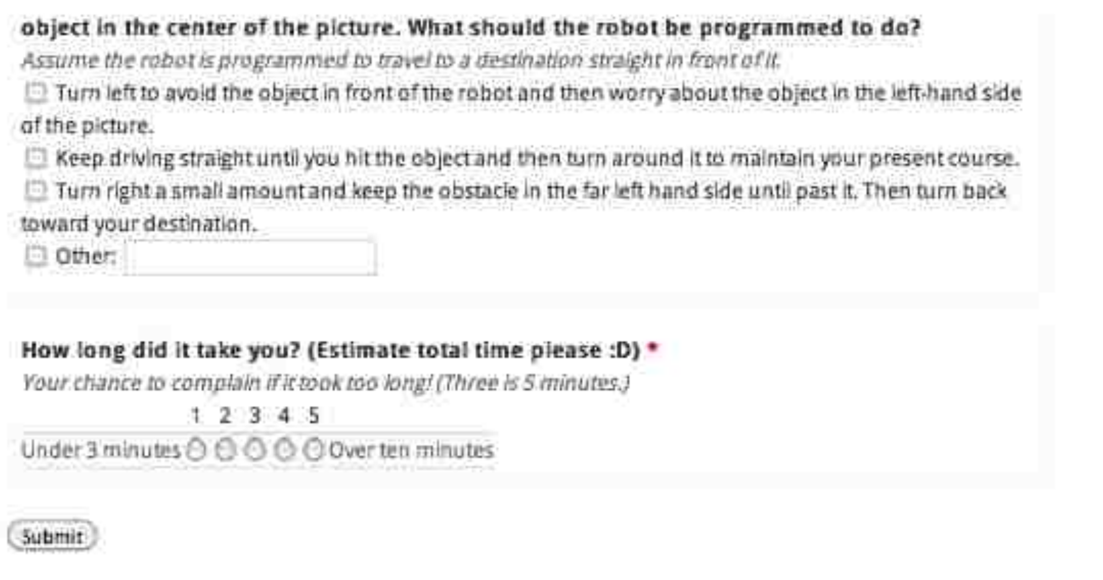
This is in reference to the camera system. If you have never heard of a blob, just put "N/A."

Define what a vision system is.

Just purpose and and what sensors are used.

The robot camera sees a large object in the left half of the picture. There is also a smaller

Figure A.6.3.2. Entry Level Skills Assessment Page 2


object in the center of the picture. What should the robot be programmed to do?
Assume the robot is programmed to travel to a destination straight in front of it.
- ☐ Turn left to avoid the object in front of the robot and then worry about the object in the left-hand side of the picture.
- ☐ Keep driving straight until you hit the object and then turn around it to maintain your present course.
- ☐ Turn right a small amount and keep the obstacle in the far left hand side until past it. Then turn back toward your destination.
- ☐ Other:

How long did it take you? (Estimate total time please :D) *
Your chance to complain if it took too long! (Three is 5 minutes.)

	1	2	3	4	5	
Under 3 minutes	○	○	○	○	○	Over ten minutes

Submit

Figure A.6.3.2. Entry Level Skills Assessment Page 2

A.7. EDUCATIONAL CONSENT FORM

Researcher: Matt Strautmann

Project:

My project is to observe how the study of robotics can increase the ability to apply science and math to practical situations. Learning modules will prepare for participation in yearly Botball competition. Concepts will include gearing, wheel dynamics, control techniques, camera blob recognition, and vision systems for obstacle avoidance.

Procedure:

Participants will begin each session with a review of fundamental concepts of Botball and programming elements. This will be a review of past components to prepare for new material. Participants will engage in groups in completing a simplified version of the last year's Botball competition. Then for the next six sessions, the participants will learn concepts that they can apply to the Botball competition. At the end of each session, a verbal questionnaire will be given to the groups to ascertain impact and applicability of training. They will then complete the same simplified version of the Botball competition again to perform comparison.

Risks: There are no risks directly related to participating in this research.

I _________________ agree to let researchers use my comments and my performance scores in publications and presentations of these results, with the understanding that my name will not be associated with the data in scoring, analysis, publication, or presentation.

Signed ___________________________________

Name (Printed) ________________________________

Student Identification ________________________________

Date: ____________

A.8. IRB FORM

APPLICATION TO THE UNIVERSITY OF MISSOURI-ROLLA CAMPUS INSTITUTIONAL REVIEW BOARDFOR THE PROTECTION OF HUMAN SUBJECTS IN RESEARCH (UMRIRB-1)

Review Requested : Exemption [x] pedited [ ] ıll Board [ ]

1a. Primary Investigator: Matthew Strautmann

Daytime Phone Number: 573-202-9315

Mailing Address: 301 E 17th Street

City/State/Zip: Rolla, MO 65401

E-Mail Address: Masc77@mst.edu

Department: ECE

1b.Additional Applicant(s):

1c.Advisor: Daytime Phone Number:

Dr. Donald Wunsch II	573-341-4521

Advisor's E-Mail Address: Department:

dwunsch@mst.edu	CPE

Campus Mailing Address:

131 Emerson Hall

2. Project Period: From Feb 2011 May 2011

3. Funding Source(s): N/A

4. Site of Work:

Toomey Hall third floor Lab

Educational Robotics: Using the Lego Mindstorms NXT Platform for Increasing High School STEM Education

5a. Title of Project:

5b. Brief description of its general purpose:

The project is a study of the learning paradigms of high school students in the fields of science, technology, engineering, and math (STEM). I will be teaching the study participants concepts that have direct applicability to the high school robotics competition, Botball. The training will focus on increasing their competency in STEM topics to be evaluated based on their performance in the Botball competition. The training will be to teach the participants the basics of a technique that is not well understood through the teaching of a traditional high school level class or a concept that is typically taught to college seniors in engineering robotics classes. The training philosophy will be to introduce the material to the participant, give them a project to demonstrate and work through the concept, and further material to pursue.

How will the subjects be selected and recruited? (Append copy of letter, ad, or transcript of verbal announcement.)

All interested parties will be accepted with only inclusion criteria being that the interested party be currently in high school. No selection within this group will be practiced. The procedure is to ask for volunteers from the currently formed (with same inclusion criteria) high school robotics club formed by Mechanical Engineering professor Dr. J. Keith Nisbett last year with express purpose of learning about robotics.

b) What inducement is offered?

No inducements offered.

Number and salient characteristics of subject, i.e., age range, sex, institutional affiliation, other pertinent characterizations.

The participant pool is the current high school robotics club sponsored through the Mechanical Engineering professor Dr. J. Keith Nisbett. The only qualification for this club is to be in high school. No gender, ethnic, affiliation, or characteristic restrictions are present. The typical age for a high school student is 14-18 years.

d) If a cooperating institution (school, hospital, prison, etc.) is involved, has written permission been obtained? (Append letters).

N/A

e) Number of times observations will be made?

2 times per training module with an initial and final assessment for finding overall training trends for a total of 14 observations.

What do the subjects do, or what is done to them, in the study? (Append copy of questionnaires or test instruments, description of procedure to be conducted on the subject.

Subjects will be participating in group training and then given Lego NXT kits to experiment with and perform small lab modules to test understand of training.

Is it clear to the subject that their participation is voluntary, that they may withdraw at any time, and that that they may refuse to answer any specific question that may be asked them?

YES

h) Number of subjects to be used in the project: Approximately 10-15

Please indicate below if any of your proposed subjects might fit into the following categories:

Minors? Yes Age 15-19

Incompetent Persons? No

Pregnant Women? No

Students? Yes

Women of Child-Bearing Age? No

Low-Income Persons? No

Institutionalized Persons? No

Minorities? No

j) Cite your experience with this type of research.

I taught a freshman introduction to engineering class at North Carolina State University for the ECE department there for one semester. I am currently studying robotics and related computational intelligence topics in my Masters degree in Electrical Engineering. I also spent half of the 2010 summer working in a junior high youth camp in TX called Pine Cove as a counselor.

How do you intend to obtain the subjects' informed consent? If in writing, attach a copy of the consent form. If not in writing, include a written summary of what is to be said to the subject(s), and justify the reason that oral, rather than written, consent is being used. Also, explain how you will ascertain that the subjects understand what they are agreeing to.

I intend to use a written consent form to ask the parents for permission. To ascertain the subjects understanding of the content, the consent form will have an attached description of all training modules, general schedule, and topics covered.

8. In your view, what benefits may result from the study that would justify asking the subjects to participate?

The club exists to use robotics to expand the participant's knowledge and ability to apply topics in Science, Technology, Engineering, and Math (STEM). The knowledge vehicle is a high school robotics competition called Botball. My study will teach the students advanced robotics knowledge beyond what they have covered in school or in the club. Their benefit is the increase in knowledge of robotics: both techniques and concepts and applications. My study will benefit in observing how this progresses.

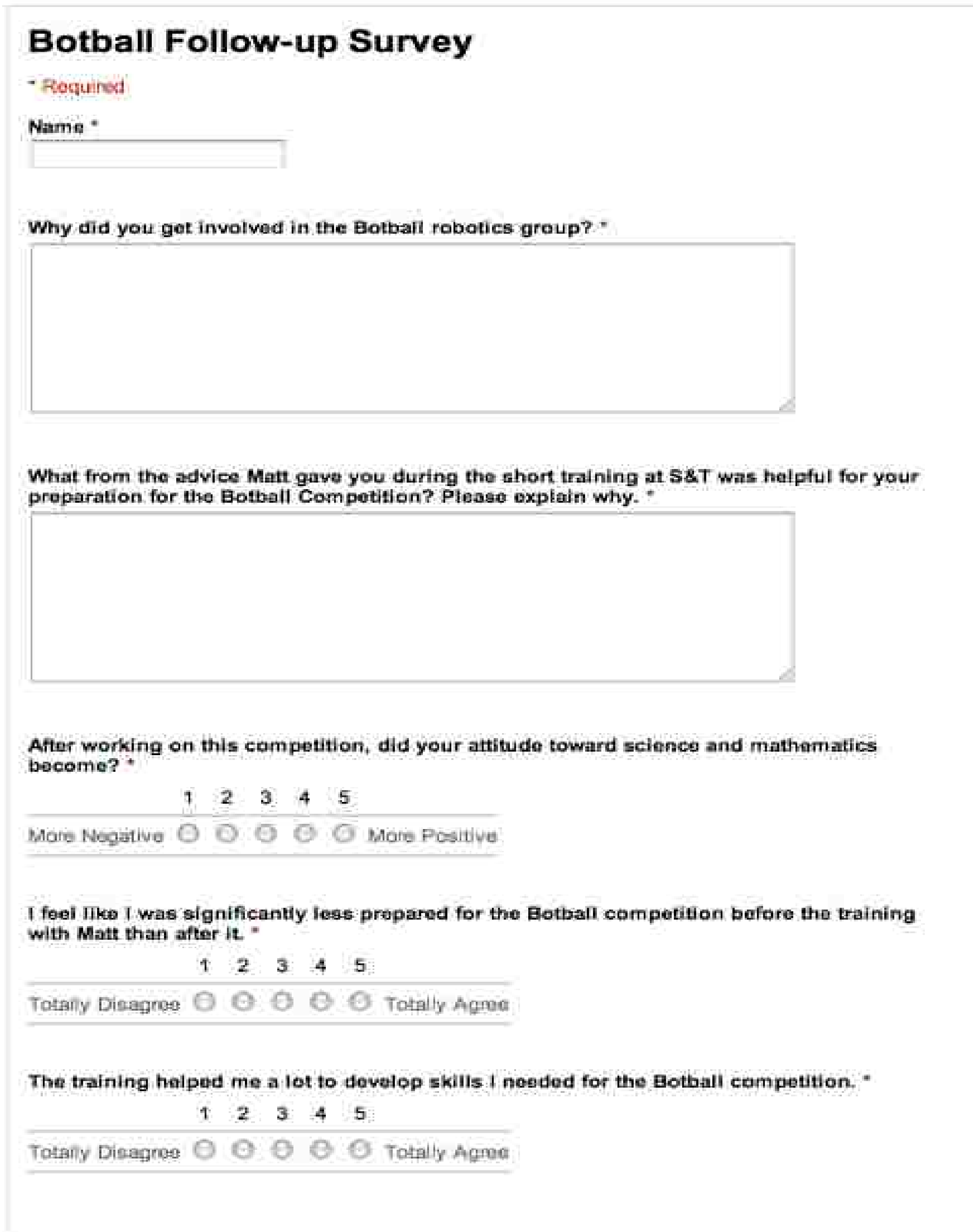
subject feel demeaned or embarrassed or worried or upset? Social? (Possible loss of status, privacy, reputation?)

There is no chance that the subjects might be harmed in any way. All material is commercial available in kits and applicable for this age group. The study will not deceive them. The purpose is to watch and observe. The observations will not demean or upset the students. They will simply record process and performance of each group.

9b. How do you ensure confidentiality of information collected? (Consider 9a and 9b from the point of view of the subject.)

All participants will be divided into two groups and each group data recorded based on group name, without record of individual participant. Participants within groups will be linked in separate document stored separately in my office. Participants will not be shown instructor evaluation rubrics.

A.8. Botball Competition Follow-up Survey



Botball Follow-up Survey

* Required

Name *

Why did you get involved in the Botball robotics group? *

What from the advice Matt gave you during the short training at S&T was helpful for your preparation for the Botball Competition? Please explain why. *

After working on this competition, did your attitude toward science and mathematics become? *

	1	2	3	4	5	
More Negative	○	○	○	○	○	More Positive

I feel like I was significantly less prepared for the Botball competition before the training with Matt than after it. *

	1	2	3	4	5	
Totally Disagree	○	○	○	○	○	Totally Agree

The training helped me a lot to develop skills I needed for the Botball competition. *

	1	2	3	4	5	
Totally Disagree	○	○	○	○	○	Totally Agree

Figure A.8.1. Botball Competition Follow-up Survey

After the training with Matt, I was completely ready for the building and programming phase of the project. *

	1	2	3	4	5	
Totally Disagree	○	○	○	○	○	Totally Agree

I find science and mathematics fun? *

	1	2	3	4	5	
Totally Disagree	○	○	○	○	○	Totally Agree

Rate your level of involvement in preparing the robots for the competition. *

	1	2	3	4	5	
Low	○	○	○	○	○	High

How would you rate the team's performance in the Botball competition? *

	1	2	3	4	5	
Subpar	○	○	○	○	○	Excellent

How would you rate your confidence in your ability to do robotic activities in the future? *

	1	2	3	4	5	
Low	○	○	○	○	○	High

Submit

Figure A.8.2. Botball Competition Follow-up Survey

A.9. Recorded Data

Table A.9.1. Botball Competition Survey Data

Student Number	I feel like I was significantly less prepared for the Botball competition before the training with Matt than after it.	After the training with Matt, I was completely ready for the building and programming phase of the project.	Rate your level of involvement in preparing the robots for the competition.	Why did you get involved in the Botball robotics group?
1	2	4	4	I felt that it would be a great learning experience for me in the science field, but more importantly in team-work, organization, patience, and leadership.
2	4	4	5	because i though it would be a fun extracurricular activity, and also something that would give me useful skill sets. i had had some robotics experience with first, so i knew to some extent whether i would enjoy it or not
3	4	4	5	Because I wanted to learn how to program and already enjoyed building various things.
4	4	2	2	To add variety to my thinking patterns.
5	4	1	2	Because they needed a girl on the team and I was willing to learn something new.

6	3	3	2	Because I enjoy robotics.

Table A.9.2. Botball Competition Survey Data

Student Number	**After working on this competition, did your attitude toward science and mathematics become?**	**How would you rate the team's performance in the Botball competition?**	**What from the advice Matt gave you during the short training at S&T was helpful for your preparation for the Botball Competition? Please explain why.**
1	4	4	The presentation about ramp functions was very helpful. We found ramp functions to make a big difference in reliability.
2	5	4	most of the things he taught were , at least for me, a really good review of principles i had already heard of, just making sure i fully understood them, and could effectively apply them
3	4	4	Using Math calculations to figure out turning arcs ect. We used several functions that calculated your turns and stuff automatically. Matt taught us how to calculate some of these.
4	4	4	The explanation about the gears and stuff helped me understand why you need so many gears on the robot.
5	3	5	Plan ahead. Because it was very necessary.
6	4	5	N/A

Table A.9.3. Botball Competition Survey Data

Student Number	**How would you rate your confidence in your ability to do robotic activities in the future?**	**The training helped me a lot to develop skills I needed for the Botball competition.**	**I find science and mathematics fun?**
1	4	2	3
2	4	5	3
3	4	4	4
4	2	3	3
5	1	3	2
6	4	3	4

Table A.9.3. ELA Gearing Questions Data

ELA		
	POST-ELA	
	gearing	
	quest 1	quest 2
Question Type:	Short Answer	Fill in the blank
Question:	What is a gear ratio?	If the gear on the motor shaft is bigger than the second gear, is the second gear going to spin faster or slower than the gear on the motor shaft?
Coding Scale:	1 - N/A	1 - N/A
	3 - partial understanding	3 - answer flipped (slower)
	5 - output/input teeth count	5 - faster
STUD1	5	5
STUD2	5	5
STUD3	1	3

STUD4	5	5
STUD5	5	5
STUD6	1	5
	PRE-ELA	
	gearing	
	quest 1	quest 2
STUD1	5	5
STUD2	5	5
STUD3	1	1
STUD4	1	5
STUD5	1	1
STUD6	1	5

Table A.9.4. ELA Wheel Dynamics Data

ELA	**POST-ELA**		
wheel dyn			
	quest 1	quest 2	quest 3(Q.#6)
Question Type:	Short Answer	Multiple Choice	Short Answer
Question:	Explain how wheel rotations can be used to determine how far a robot has traveled.	If two motors are used to drive a robot without any tuning of the robot or motors, will the robot drive in a straight line? Why or why not?	What is a ramp function?
Coding Scale:	1 - N/A	1 - N/A	1 - N/A
	3 - involves circumference and rotations…	3 - its not that important	3 - gradual increase in speed

	5 - circ.*rotations = distance	5 - all motors/sensors are different and must be checked	5 - function…scales input between 0 and 100
STUD1	5	5	4
STUD2	4	5	4
STUD3	5	3	3
STUD4	5	5	1
STUD5	1	5	4
STUD6	5	5	4

POST-ELA - wheel dynamics			
	quest 1	quest 2	quest 3(Q.#6)
STUD1	5	5	5
STUD2	5	5	5
STUD3	4	1	1
STUD4	3	1	1
STUD5	5	1	1
STUD6	5	5	3

Table A.9.5. ELA Motion Control Data

ELA	**POST-ELA**	
Motion controls		
Question:	What is a control system? Give an example if possible.	Explain how a robot can follow a line using only a light sensor to tell the robot if the space under the sensor is a line or not?

Coding Scale:	1 - N/A	1 - N/A
	3 - just example	3 - turn toward color
	5- example with definition	5 - left for white color values and right for dark color values from light sensor
STUD1	4	5
STUD2	5	5
STUD3	5	5
STUD4	5	5
STUD5	5	5
STUD6	1	5
PRE-ELA -controls		
	quest 1	quest 2
STUD1	5	5
STUD2	3	5
STUD3	3	5
STUD4	1	1
STUD5	1	1
STUD6	4	5

Table A.9.6. ELA Blob Recognition Data

ELA	**POST-ELA**			**time scale**
blob				1-5
	quest 1	quest 2	quest 3	Fill in the blank
Question Type:	Short Answer	Short Answer	Mulitple Choice	How long did it take you? (Estimate total time please :D)

Question:	What is a blob?	Define what a vision system is.	The robot camera sees a large object in the left half of the picture. There is also a smaller object in the center of the picture. What should the robot be programmed to do?	
Coding Scale:	1 - N/A	1 - N/A	1 - N/A	
	3 - a color	3 - something that sees colors/blobs	3 - drive over the obstacle!	
	5 - grouping of pixels of same color	5 - description of purpose and function	5 - turn till vision doesn't see and then turn back afterward	
STUD1	5		5	1
STUD2	5	4	5	2
STUD3	5	1	1	2
STUD4	1	5	5	3
STUD5	3	1	5	5
STUD6	3	5	5	2

PRE-ELA -blob		**time scale**		
	quest 1	quest 2	quest 3	1-5
STUD1	5	5	3	2
STUD2	4	5	4	2
STUD3	4	5	1	4
STUD4	1	5	1	2
STUD5	1	5	1	4
STUD6	5	3	5	2

Mechanics of Gearing

Instructor Estimations

Table A.9.7. Nomenclature Data

Nomenclature/Terminology								
Coding Scale: 1 - No knowledge		3 - recognition and definition			5 - Identify/Understand properties and know application possibilities			
	spur gear	rack and pinion gear	worm gear	teeth placement and function	teeth meshing	gear ratio equation	gearing force	gearing speed
STUD1	5	5	5	5	5	5	5	5
STUD2	5	5	5	5	5	5	5	5
STUD3	5	4	5	5	5	5	5	5
STUD4	3	3	3	5	5	5	5	5
STUD5	3	3	3	3	4	5	4	4

Table A.9.8. Application of Concept Data

Application of Concept	apply gearing to botball competition	apply gearing to problems in general
Coding Scale:	1 - N/A	1 - N/A
	3 - understand concept application but struggle with recognizing situations in Botball	3 - general application skills but struggle to recognize application situations

	5 - can easily recognize application situations in Botball	5 - good application skills
STUD1	5	5
STUD2	4	5
STUD3	4	4
STUD4	3	3
STUD5	3	3

Table A.9.9. Assessment Ratings Data

Assess-ment Ratings	Completed Gearing Assessment	Performance for question 1: Revolutions for traveling 3ft.	Performanc e on quest 2: Effects of vehicle load on traction	Perceived knowledge of topic improvem ent from Assessme nt	Perceived level of understanding of assessment concept
Coding Scale:	1 - N/A	1 - N/A	1 - N/A	1 - N/A	1 - N/A
	3 - Partial Completion	3 - Vehicle off by more than 1 inch	3 - Partial accounting for load	3 - improved in some areas	3 - needed instructor input to complete assessment
	5 - Completion	5 - Vehicle within 1 in of target distance	5 - full accounting for traction loss	5 - much improved in all areas especially in application of concepts	5 - understood assessment goal and steps based on tutorial and instructions
STUD1	5	5	5	2	5
STUD2	5	5	5	3	5
STUD3	5	5	5	4	4
STUD4	5	5	5	3	3
STUD5	5	5	5	3	3

Table A.9.10. Perceived Benefit Rating Data

Perceived Benefit Ratings	Self-Discovery of concept material (tutorial, etc.)	Assessment Exercise Perceived Benefit	Perceived Function of module for Improvement in Performance in Botball Competition
Coding Scale:	1 - N/A	1 - N/A	1 - N/A
	3 - Some Benefit	3 - Some Benefit	3 - Some Improvement
	5 - Very Beneficial	5 - Very Beneficial	5 - Much Improvement
STUD1	2	2	3
STUD2	4	4	4
STUD3	5	5	5
STUD4	2	4	3
STUD5	3	4	3

Table A.9.11. Student Data

Student Perception								
Nomenclature								
	spur gear	rack and pinion gear	worm gear	teeth placement and function	teeth meshing	gear ratio equation	gearing force	gearing speed
STUD1	5	5	5	5	5	5	5	5
STUD2	5	5	5	5	5	5	5	5
STUD3	5	5	5	5	5	5	3	3
STUD4	5	5	5	5	5	5	5	5
STUD5	5	5	5	5	5	5	5	5

Application of Concept		
	application of gearing to botball	application of gearing to problems in general
STUD1	5	5

STUD2	4	5
STUD3	4	3
STUD4	5	5
STUD5	5	5

Assessment Rating					
	Completed Gearing Assessment	Performance for question 1: Revolutions for traveling 3ft.	Performance on quest 2: Effects of vehicle load on traction	Perceived knowledge of topic improvement from Assessment	Perceived level of understanding of assessment concept
STUD1	5	5	5	5	5
STUD2	5	5	4	3	5
STUD3	5	5	5	4	5
STUD4	5	5	5	5	5
STUD5	5	5	5	5	5

Perceived Benefit Rating			
	Self-Discovery of concept material (tutorial, etc.)	Assessment Exercise Perceived Benefit	Perceived Function of module for Improvement in Performance in Botball Competition
STUD1	4	3	4
STUD2	3	3	5
STUD3	4	4	4
STUD4	4	3	4
STUD5	4	3	4

Wheel Dynamics

Instructor Estimations

Table A.9.12. Wheel Dynamics Nomenclature Data

Nomenclature/ Terminology				
Coding Scale: 1 - No knowledge				

3 - recognition and definition				
5 - Identify/Understand properties and know application possibilities	explain wheel dynamics topic contents and effects on robot performance	explain how motor voltage effects on driving accuracy	motor torque effects	speed vs. traction of robot
STUD1	5	5	5	5
STUD2	4	3	5	5
STUD3	4	3	5	5
STUD4	3	2	5	4
STUD5	3	2	3	3

Table A.9.13. Wheel Dynamics Application of Concept Data

Application of Concept	apply wheel dynamics to botball competition	apply wheel dynamics to problems in general
Coding Scale:	1 - N/A	1 - N/A
	3 - understand concept application but struggle with recognizing situations in Botball	3 - general application skills but struggle to recognize application situations
	5 - can easily recognize application situations in Botball	5 - good application skills
STUD1	4	5
STUD2	5	4
STUD3	5	5
STUD4	3	3
STUD5	2	2

Table A.9.14. Wheel Dynamics Assessment Ratings Data

Assessment Ratings	Completed Wheel Dynamics Assessment	Performance for question 1: equalizing wheel speeds with wheel voltages	Performance on quest 2: Calculating wheel speed for turning	Perceived knowledge of topic improvement from Assessment	Perceived level of understanding of assessment concept
Coding Scale:	1 - N/A	1 - N/A	1 - N/A	1 - N/A	1 - N/A
	3 - Partial Completion	3 - greater than one inch error	3 - greater than one inch error radian error	3 - improved in some areas	3 - needed instructor input to complete assessment
	5 - Completion	5 - error less than one inch	5 - error less than one inch radian error	5 - much improved in all areas especially in application of concepts	5 - understood assessment goal and steps based on tutorial and instructions
STUD1	5	5	5	5	2
STUD2	5	5	5	4	5
STUD3	5	5	5	5	5
STUD4	4	3	3	3	4
STUD5	4	3	3	3	3

Table A.9.15. Wheel Dynamics Perceived Benefit Ratings Data

Perceived Benefit Ratings	Self-Discovery of concept material (tutorial, etc.)	Assessment Exercise Perceived Benefit	Perceived Function of module for Improvement in Performance in Botball Competition

Coding Scale:	1 - N/A	1 - N/A	1 - N/A
	3 - Some Benefit	3 - Some Benefit	3 - Some Improvement
	5 - Very Beneficial	5 - Very Beneficial	5 - Much Improvement
STUD1	2	2	3
STUD2	3	3	4
STUD3	5	4	5
STUD4	4	4	3
STUD5	3	2	2

Student Perceptions

Nomenclature

Table A.9.16. Wheel Dynamics Nomenclature Data

	explain wheel dynamics topic contents and effects on robot performance	explain how motor voltage effects on driving accuracy	motor torque effects	speed vs. traction of robot
STUD1	5	5	5	5
STUD2	4	4	4	4
STUD3	4	4	4	4
STUD4	5	5	5	5
STUD5	5	5	5	5

Application of Concept

Table A.9.17. Wheel Dynamics Application of Concept Data

	apply wheel dynamics to botball competition	apply wheel dynamics to problems in general
STUD1	4	5
STUD2	4	4
STUD3	4	4
STUD4	4	5
STUD5	4	5

Assessment Ratings

Table A.9.18. Wheel Dynamics Assessment Ratings Data

	Completed Wheel Dynamics Assessment	Performance for question 1: equalizing wheel speeds with wheel voltages	Performance on quest 2: Calculating wheel speed for turning	Perceived knowledge of topic improvement from Assessment	Perceived level of understanding of assessment concept
STUD1	5	5	5	4	5
STUD2	5	4	4	5	4
STUD3	5	4	4	5	4
STUD4	5	5	5	4	5
STUD5	5	5	5	4	5

Perceived Benefit Rating

Table A.9.19. Wheel Dynamics Perceived Benefit Rating Data

	Self-Discovery of concept material (tutorial, etc.)	Assessment Exercise Perceived Benefit	Perceived Function of module for Improvement in Performance in Botball Competition
STUD1	5	4	5
STUD2	4	4	4
STUD3	4	4	4
STUD4	5	4	5
STUD5	5	4	5

Motion Control

Motion Control - Instructor Estimation

Nomenclature

Table A.9.20. Motion Control Nomenclature Data

Coding Scale: 1 - No knowledge				
3 - recognition and definition				
5 - Identify/Understand properties and know application possibilities	explain on/off control theory	explain graduated control theory	explain proportional control theory	explain motion control theory and application
STUD1	5	5	5	5
STUD2	5	5	5	5
STUD3	5	5	5	5
STUD4	4	4	4	3
STUD5	5	3	3	3
STUD6	5	4	5	5

Table A.9.21. Motion Control Application of Concept Data

Application of Concept	apply motion control to botball competition	apply motion control to problems in general
Coding Scale:	1 - N/A	1 - N/A
	3 - understand concept application but struggle with recognizing situations in Botball	3 - general application skills but struggle to recognize application situations
	5 - can easily recognize application situations in Botball	5 - good application skills
STUD1	5	5
STUD2	5	5
STUD3	4	4
STUD4	3	3
STUD5	2	2
STUD6	5	5

Table A.9.22. Motion Control Assessment Ratings Data

Assessment Ratings	Completed Motion Control Assessment	Performance for question 1: differences between control programs	Performance on quest 2: on/off control program	Performance for question 3: graduated control program
Coding Scale:	1 - N/A	1 - N/A	1 - N/A	1 - N/A

	3 - Partial Completion	3 - recognized some differences in performance	3 - explain on/off but not understand program output	3 - explain graduated control but not understand program output
	5 - Completion	5 - accurate differences seen between program outputs	5 - explain on/off control process as implemented by program	5 - explain graduated control process as implemented by program
STUD1	5	5	5	5
STUD2	5	5	5	5
STUD3	4	5	5	5
STUD4	5	5	4	4
STUD5	5	5	3	3
STUD6	5	5	4	4

Table A.9.23. Motion Control Assessment Ratings Continued Data

Assessment Ratings Cont.	Performance on quest 4: proportional control program	Perceived knowledge of topic improvement from Assessment	Perceived level of understanding of assessment concept
Coding Scale:	1 - N/A	1 - N/A	1 - N/A
	3 - explain proportional but not understand program output	3 - improved in some areas	3 - needed instructor input to complete assessment
	5 - explain proportional control process as implemented by program	5 - much improved in all areas especially in application of concepts	5 - understood assessment goal and steps based on tutorial and instructions
STUD1	5	5	4
STUD2	5	5	5

STUD3	4	5	5
STUD4	3	4	2
STUD5	3	3	4
STUD6	4	4	4

Table A.9.24. Motion Control Perceived Benefit Ratings Data

Perceived Benefit Ratings	Self-Discovery of concept material (tutorial, etc.)	Assessment Exercise Perceived Benefit	Perceived Function of module for Improvement in Performance in Botball Competition
Coding Scale:	1 - N/A	1 - N/A	1 - N/A
	3 - Some Benefit	3 - Some Benefit	3 - Some Improvement
	5 - Very Beneficial	5 - Very Beneficial	5 - Much Improvement
STUD1	5	5	5
STUD2	5	4	4
STUD3	5	5	5
STUD4	3	3	3
STUD5	3	4	3
STUD6	5	5	5

Motion Control - Student Perceptions

Nomenclature

Table A.9.25. Motion Control Nomenclature Data

	explain on/off control theory	explain graduated control theory	explain proportional control theory	explain motion control theory and application
STUD1	5	5	5	5
STUD2	5	5	5	5
STUD3	5	5	5	5
STUD4	5	5	5	4
STUD5	5	5	5	5

STUD6	5	5	4	5

Application of Concept

Table A.9.26. Motion Control Application of Concept Data

	apply motion control to botball competition	apply motion control to problems in general
STUD1	5	5
STUD2	5	5
STUD3	5	5
STUD4	5	5
STUD5	4	5
STUD6	3	5

Assessment Ratings

Table A.9.27. Motion Control Assessment Ratings Data

	Completed Motion Control Assessment	Performance for question 1: differences between control programs	Performance on quest 2: on/off control program	Performance for question 3: graduated control program
STUD1	5	5	5	5
STUD2	5	5	4	5
STUD3	5	5	5	5
STUD4	5	5	4	4
STUD5	5	5	5	5
STUD6	5	5	5	5

Assessment Ratings Cont.

Table A.9.28. Motion Control Assessment Ratings Cont. Data

	Performance on quest 4: proportional control program	Perceived knowledge of topic improvement from Assessment	Perceived level of understanding of assessment concept
STUD1	5	5	5
STUD2	5	5	4
STUD3	5	5	5
STUD4	5	5	1
STUD5	5	5	1
STUD6	5	5	3

Perceived Benefit Ratings

Table A.9.29. Motion Control Perceived Benefit Ratings Data

	Self-Discovery of concept material (tutorial, etc.)	Assessment Exercise Perceived Benefit	Perceived Function of module for Improvement in Performance in Botball Competition
STUD1	4	4	4
STUD2	5	5	5
STUD3	5	4	5
STUD4	1	1	1
STUD5	5	1	1
STUD6	3	3	3

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