Mathematics applied when experimenting with Robots

Robotics provides a hands-on-mind-on set of lessons that reinforce and teach STEM concepts in an engaging and concrete manner. In table 1 below you will find an applied robotic application that is measurable on the left and the mathematic concept that can be taught on the right.

Table 1

Application	Mathematics Concept Demonstrated
Calculating distance traveled based on the number of rotations of an axle and the diameter of a wheel attached to the axle	Circle geometry (Diameter, Circumference) **C = π*d** Measurement Distance – centimeters Unit conversion – between systems (centimeters to inches), within systems (centimeters to meters), etc. 1 rotation = 360 degrees = X cm = Y in. (values of X and Y are calculated based on wheel size) Operations Define a procedure to convert cm into rotations
Calculating speed and acceleration using a variety of different methods (stopwatch, meterstick, software control, datalogging and graphs)	Speed equation (d=rt), variables and constants, graphs
Analyzing data collected on trial runs while conducting experiments	Central tendency (mean of 3 data values (a+b+c)/3 as a representative value) Goodness of fit – Percent error calculation: $\frac{\lvert theoretical\ measurement - actual\ measurement \rvert}{theoretical\ measurement}$
Predicting, based on discovered or proposed linear/proportional relationships, the distance or speed the robot will travel when changing wheel sizes/RPM of the robot/or the number of rotations of the axle	Ratios and proportions **(** $\frac{a}{b} = \frac{2a}{2b}$ **)** Direct linear relationship y = ax Inverse linear relationship y = a/x Graphing, interpolation, extrapolation
Basic programming – conditional statements, calculating thresholds, passing equations in experiments	**Boolean logic**, Thresholds, Averages (means), Comparisons **(<, >, <=, >=, ==, !=)**, **Operations (+, -, ×, ÷, |x|)**
Path Planning/robot navigation– given several locations and variables write a program using the appropriate mathematical formulas to move from point to point.	Applied pre-algebra, algebra, geometry, trigonometry
Written explanation of the mathematics the student just used to solve the problem	Communication – Identify and communicate relevant math concepts used, including formulas, calculations, data, and results
Robot Mapping Scanning and mapping using the ultrasonic sensor	**Angles, Graphing, Measurement** **Polar coordinates** (very basic)**, Plotting in polar**
Robotic Calipers Calculate the size and mass of a tree based on a cylindrical model, and automated measurements.	Measurement, Mass, Volume, Density, Geometry of solids, Circle/cylinder density, Gear ratios, Physical modeling, Approximations

Table 1 continued

Application	Mathematics Concept Demonstrated
Gather data in a table, plot data on a graph, then calculate a linear regression using Excel; use the graph and equation to take future measurements	Tables, graphs, interpolation, extrapolation, linear regression, computational tools, calibration
Counting lines that the robot runs across	Variables, operations, and formulas
Predicting rates of occurrence of combinations of events on spinner wheels	Probability, compound probability

Science applied when experimenting with robots

In table 2 below Carnegie Mellon's Robotics Academy has developed a set of robotic investigations that engage students in scientific analysis where students apply scientific process investigate/research scientific concepts.

Table 2

Application	Science Concept Demonstrated
Investigation Identifying a question, formulating a possible explanation (with scaffolded guidance), collecting data to test the hypothesis, analyzing the data, drawing conclusions.	Experimental Design • hypothesis • independent variables • dependent variables • control variables • experimental conditions • multiple trials • evidence Numeric Analysis • error • %error Estimates and approximation Collecting and analyzing data collected on trial runs while conducting experiments
Examine the behavior of the Sound Sensor	• Sound and waves • Amplitude vs. frequency • Sounds vs. human perception dB/dBA via • Decibels • Data acquisition • Analysis
Programming and Modeling Light sensor Line-Tracking Behaviors	Light and reflectivity Observation and Predictions Perception of light/dark Modeling (of robot behavior, extended and refined several times) Color and perception (human vs. light sensor, reflectivity of different wavelengths)
Defining the performance envelope of the Ultrasound sensor	Measurement (distance) Ultrasound and sound waves Plotting data **Outliers error** Spatial Graph Model (Ultrasonic detection area)

Table 2 continued

Application	Science Concept Demonstrated
Designing robots - Form follows function	Mass, Speed, Equilibrium (forces in equilibrium = top speed, stall point), Measurement (mass, forces, speed), Center of Mass, Support Polygon, Balance, balanced and unbalanced forces
Analyzing robot's drive train – gears/gear ratios/compound gear ratios	**Torque, Gears/Gear Ratios/Mechanical Advantage/Simple Machines, Idler Gears**
Discover and describe how touch sensors work	**Basic circuits** Direct Current Load Conductors Switch Power Supply
Testing and describing how motors and generators work	**Magnetism** **Electromagnet** **Electromagnetic induction**
Gathering user testing data about the success of a robot's ability to communicate with people	Social Science methods (surveys, observational analysis)
Remote Control	Resonance Crystals Frequency
Engineering Design Inquiry – Design-motivated project based learning	Inquiry processes in practice, Science and Technology
Written explanation of results, design decisions, experimental results, and scientific process	Communication – Communicate relevant science process and content concepts visited during the investigations
Measuring the cooling rates of water in different containers	Thermodynamics, specific heat, thermal conductivity
Comparing the effectiveness of different cooling methods on water	Convection cooling, experimental process
Estimating/determining the concentration of insoluble material in water by measuring opacity (turbidity)	Light, refraction, solutions, solubility, water quality
Monitoring the temperature of air, soil, and water during a day-night cycle using data logging	Earth science, heat, temperature, energy, specific heat
Measuring the free-falling speeds of different objects	Gravity, air resistance, aerodynamics
Underwater-themed challenges in Aquabots Camp-on-a-Disk product	Oceanography
Nature-themed challenges in Dataloggers Camp-on-a-Disk product	Ecology/Environmental Studies

Technology Education

Robotics serves as an excellent integrator for teaching technological literacy as well as reinforcing mathematical and scientific competency. Table 3 shows fundamental lessons that can be implemented in a well designed robotic class.

Table 3

Application/Lesson	Technological Concept
Safety	Human factors • Creating a safe environment • Safety as an attitude • Legal implications • Using tools and machinery • Designing with safety in mind
Technology and Society	Robot impact on society Types of robot interactions - Communication Technology (robot-human and human-human via robot) Expected and unexpected consequences of robotic development Impact on jobs (jobs created – jobs replaced)
Career choices	Career preparation Administration Sales Marketing Engineering Programming Technician Entrepreneur
Understanding robotic systems	The concept of systems – Motors (output), Controller, Sensors (input, feedback), Program, Mechanical elements
Robot design	Engineering process model • Input-Process-Output-Feedback • Form follows function • Design tradeoffs (Drive train design, sensor integration, motor choices, remote vs. autonomous) • Testing & Revision
Controlling robotic systems	**Control** • Behaviors • Timers/Wait states • Conditional statements • Loops • Remote control • Bluetooth
Team problem solving	**Teamwork skills** • Cooperative learning • Differentiated roles and specialization
Managing a project	Project management • Time management/scheduleing • Resource allocation/budgeting • Systems analysis • Information accessing

Table 3 continued

Application/Lesson	Technological Concept
Sensors • How they work - Math and scientific principles behind sensor design • Type of feedback to expect • Designing sensor • Application	Sensor types and applications • Touch • Light • Encoder • Ultrasound • Infrared • Sound
Communications • Written • Digital multimedia • Presentation	Summative – Evaluate and present the capabilities and appropriateness of the technology to the problem presented

Communications

There are many rich opportunities to reinforce critical thinking, communication, and writing skills in robotics. Table 4 below lists several opportunities.

Table 4

Activity	Communications
Engineering Design Notebook	most questions require written explanation in addition to calculations or programming, general teamwork skills, build technical vocabulary, create logical notes and summaries
Written description of technological/scientific/ or mathematic concept	• Descriptive/Explanatory Composition: Describing behaviors, verbalize the functionality of parts of the program • Describe patterns of turning motion, compare and contrast two different types of turns • Recording data in a table, evaluation of methods, predictions, describing robot behavior, describing a proportional relationship • Verbalize troubleshooting processes, analyzing and describing an unexpected situation or observation • Make predictions using a model, extend and revise the model • Compare/contrast design choices, documenting and recording steps, explanation of why this was the best choice • Describe the effects of gears • Describe a design concept, explain the significance of center of mass to the design • Expository writing: How the machine works • Research, examine and evaluate real-world robot applications, predict the future, justify your predication • Describe a complex programming concept (multitasking) • Develop a marketing plan for a robot technology • Persuasive/Explanatory Composition: Justify a design choice
Technical report	Recording data, organizing data in tables, explaining scientific reasoning, arguing support/dissent for a hypothesis using data, extracting information from a written scenario, explaining the importance of communication within a team