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Department of Computer Engineering

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Using LEGO MINDSTORMS in school education

6M070400– «Computing systems and software» speciality

Kaskelen, 2013

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Master dissertation

Using LEGO MINDSTORMS in school education

6M070400– «Computing systems and software» speciality

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ABSTRACT

Nowadays problem of teaching is the question how to engage students in the process of learning new material with an enthusiasm. Reason to this may be different factors such as students' disinterest or, in most cases, laziness or passiveness. Schools may keep on teaching the same material taken from library year by year, but at some moment, this material will not be the only way to make people study it. When we are used to something for a long time, we will probably get tired of it. Moreover, this is key point of this problem; students need interesting methods of teaching. In this work, I present my vision of teaching physics by using LEGO MINDSTORMS.

Students have difficulty learning for learning's sake, especially in physics classrooms. When they have an applied, real world challenge such as an engineering problem to solve or a novel science investigation to perform, students thrive, exhibiting a great deal of enthusiasm and ownership. Allowing them to solve problems without concrete answer on an answer sheet, students learn to turn on their confidence, teamwork and problem-solving skills. Well-designed activities using robotics give students rich opportunities to write about their ideas: utilize mathematical tools and represent their findings via mathematical models. Using 3D artifacts, robotics, other construction leads students to active work. Additionally, many students are familiar with LEGO, their modular design allows for multiple solutions to a given assignment, and the sensors and motors that are compatible with LEGO MINDSTORMS allows high school physics students to engage in a very diverse set of engineering and science activities.

Using LEGO MINDSTORMS robotics activities to teach physics concepts creates an effective learning environment for conceptual knowledge development through the process of design, construction and experimental testing. Students have opportunities to develop their teamwork and communication skills and become more independent and confident learners.

РЕЗЮМЕ

В настоящее время проблема преподавания — это, как вовлечь учащихся в процессе изучения нового материала с энтузиазмом. Причиной этому могут быть различные факторы, такие как незаинтересованность или, в большинстве случаев, лень или пассивность. Когда ученики привыкли к чему-то в течение длительного времени, то вероятно, они устанут от этого. Более того, это ключевой момент от этой проблемы, поэтому мы должны разработать новые методы преподавания. В этой работе, я описал видение дальнейшего преподавания физики с помощью LEGO MINDSTORMS.

В данный момент дети имеют трудности в понимании точных наук, особенно в физике. Но когда у них есть прикладная задача, такие как инженерные проблемы, требующие решения, ученики демонстрируют большой энтузиазм и интерес. Хорошо продуманное обучение с использованием робототехники дает ученикам возможность использовать математические средства и представлять свои выводы с помощью математических моделей. Использование робототехники приводит студентов к активной работе. Кроме того, многие студенты знакомы с LEGO, их модульная конструкция позволяет иметь несколько решений определенного задания, а также датчики и двигатели, которые совместимы с LEGO MINDSTORMS позволяет учащимся школы заниматься разнообразной инженерной и научной деятельностью.

ТҮЙІН

Қазіргі заманда - сабақ берудің ең басты мәселе, ол оқушыларды жаңа тақырып түсіндергенде оларды қызықтыру. Бұлардын бәріне көп себептер бар, мысалы жалқаулық немесе тағы басқа. Оқушылар ұзақ уақытта бір нәрсеге үйренсе олар ол нәрседен шаршайды. Яғни оқушылардың қызығушылығын көтеру үшін жаңа методтар табуымыз керек. Бұл мәселені шешу үшін мен физика пәнін LEGO MINDSTORMS көмегімен өткізуын тандадым.

Оқушылар нақты ғылымды толық қабылдай алмайды, ал егер олардың қолдарына нақты инженерлік затпен жұмыс істесе ,оқушының қызығушылығы көбиеді. Жақсы ойланып істелген робототехника білімі математикалық мәселелерді шешуге мүмкін. Робототехника қолдануы оқушыларды белсенділігі жоғары болады. Бұдан басқасы студентердің көбі LEGO құрамын біледі, және олармен жұмыс істеу өте қиын келмеу тиіс. LEGO MINDSTORMS оқушыларға әр-түрлі инженерлік жұмыспен айналауға мүмкіндік береді.

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Introduction

Why physics with robotics? Two reasons - inherent to robotics is measurement and actuation. In other words, in order for a robot to interact with the world, it has to investigate and do something with that investigation. It has to apply what it has "learned". Therefore, I can say that inherent to robotics is investigation and application. The same is true for physics education. In classrooms around the world, students are going to investigate and apply what they have learned to something in the real world. Robotics gives us these two aspects of physics education in one very well connected package. Throughout this work, I will tell about opportunities to use robotics in classroom for investigation and applied physics projects.

Robotics is engaging, promotes creative problem solving, encourages students to represent their ideas in the real world with a precision system, provides excellent feedback and finally, robotics can be easily connected to knowing and learning a great diversity of physics concepts and skills.

Why LEGO® MINDSTORMS® based robotics? I have found it to be an affordable, durable, and flexible solution for our project needs. My experience with this system over one year has allowed me to develop a diversity of activities and test them in my own classroom. However, the core of my ideas will work with most any sensor/motor based robotics system.

Whether it is LEGO based or not, robotics is a great hook in a classroom environment, engaging reluctant and enthusiastic learners. I saw that this system provide students with exceptional feedback, helping them to develop their ideas and successfully tinker with physical phenomena as they endeavor to take on various science and engineering challenges. Furthermore, I observed that after class has ended, I still have students in the room. They do not want to leave. They are having a great time challenging themselves and they are often so proud of what they have made that they bring friends later in the day to see their creations.

The purpose of this work is not to replace current physics curriculum. Instead, the purpose of this work is to supplement school curriculum. I am motivated to share with teachers a set of activities centered on LEGO robotics because they work well to engage students in the process of learning the concepts and skills of physics. However, I know that every school and every class within every school is different and those differences warrant adaption. In writing this work, I wanted to focus on providing a resource from which every teacher can draw how to utilize LEGO MINDSTORMS in own classrooms. The ideas that inspired the activities of this work often came from conversations I had with my own students, fellow teachers, scientists, engineers, and other specialists in fields related to physics education. I hope that the ideas in this work inspire teachers and students to create unique and powerful learning opportunities in classroom.

The goal of this section is to describe how the tools of a LEGO MINDSTORMS robotics kit fits into a physics-learning environment. Because the work itself serves to demonstrate specifically how the LEGO MINDSTORMS kit is used in a physics class, my approach in this section is to treat the topic more generally, explaining more about why I chose these tools in my own physics classrooms. This section is also designed to be "food for thought" for teachers as they start to modify activities and invent the own. The components of a LEGO MINDSTORMS kit serve as both measurement and design tools. As a measurement tool, they are only limited by the type of sensor to which you can connect. Both the NXT and RCX can be connected to many LEGO and non-LEGO based sensors. As a design tool, they afford the student a great deal of precision in their measurements and they allow students to use the same medium for designing scientific experiments as well as solutions to engineering design challenges. What follows is a more detailed discussion of these main points.

With LEGO built light sensors, thermometers, angle sensors, microphones, and distance sensors, both the RCX and NXT serve as stand-alone measurement tools. Both the NXT and the RCX have a "view" option that allows you to see the data streaming in on any sensor directly on the device's screen. The NXT can be set-up quickly for a diversity of short and simple investigations.

With a little more effort, the NXT can be extended to display data from third party sensors.

How often do students discuss "human error" in their lab reports? How often are the data collected by students inconclusive? How often are discussions with students less about what the data are and more about what the data should be. The final point that I wish to discuss in this section about the role LEGO MINDSTORMS plays in physics classroom is the issue of accuracy and precision in robot based physics investigations.

While the robotic tools used in the activities of this work enhance student investigations and applied physics design projects, they do not take the thinking out of the process. The accuracy of a student's measurements communicates whether or not the student measured what they wanted to measure. LEGO MINDSTORMS do not necessarily make a student's measurements more accurate. Students will still need to learn and practice the essential skills of experimental design and the methods of science. They will need to determine the parameters of their experiment such as which variables to control, instruments to use, units of measurement, the duration of each run, and the number of runs. They will practice how to analyze data, reading trends and fitting appropriate models. They will practice evaluating the results of an investigation and comparing their results with their predictions.

LEGO MINDSTORMS is very helpful in improving the precision of student measurements. The precision of a set of measurements communicates how close the measurements are to each other. Precise measurements have a very small variance. NXT and RCX based experiments come in quite handy when precision is needed. If I program the robot to move for five wheel rotations, it will travel the same distance every single time. If I program the robot to move its motor at a specified speed, it will do that every single time. With the exception of low battery issues, teachers and students will be very pleased with the precision of the data collected. Experiencing the precision of data in a LEGO MINDSTORMS based investigation opens up your mind to investigations that you did not think possible before.

As a measurement tool, the NXT and RCX stand with meter sticks, stopwatches, spring scales, thermometers, digital force meters, digital motion detectors, voltmeters, ammeters, and other instruments in physics equipment inventory. However, what about the rest of the pieces that come in a LEGO MINDSTORMS kit? The LEGO blocks, beams, wheels, gears, etc. allow students to build a myriad of set-ups for investigations and applied physics projects. The projects in this work are only the tip of the iceberg.

Engineering design challenges are not new to physics classes. From paper airplanes, egg drops, water rockets, toothpick bridges and mousetrap cars, engineering challenges in physics instruction allow students the opportunity to engage in creative, enjoyable, and practical ways. Engineering design challenges gives students an opportunity to talk about physics as it relates to something they created, something practical. Engineering design challenges puts physics to use and immediately answers the question, "Why are we learning this?"

If physics teachers already do engineering design challenges, how do LEGO MINDSTORMS kits enhance this form of instruction? They maximize the ratio of equipment to project possibilities. With egg drops, toothpick bridges and mousetrap cars, teachers need to obtain and maintain a steady supply of materials, each set of materials dedicated to only a few types of projects. With LEGO MINDSTORMS the number of projects is almost limitless. Perhaps teachers will not do an egg drop project with MINDSTORMS or launch an NXT in a rocket , but with one kit of materials, teachers can do many other very engaging applied physics projects.

In this work, I emphasize the link between physics investigations and engineering design by providing activities that show students the need to investigate while taking on an engineering design challenge. For example, students will investigate gear ratios while creating a motorized crane or drag car and investigate sound waves while creating a system to make the best ear protection. By having students engaged in projects that synthesize investigations with engineering design, teachers are helping them close the gap between the concepts and skills of physics and the practical use of those skills. In closing the gap, I help students take what they learn in the classroom and use it in the rest of their lives.

1. Hardware

1.1 Introduction

The purpose of this part is to introduce teachers to the hardware and software tools that will allow them to begin to use LEGO® MINDSTORMS in physics class. This part focuses on hardware, providing background information, tips, and techniques to get started with the sensors, motors, beams, gears, and two different types of LEGO vehicles. Next part focuses on software, introducing to several software options available for programming and data logging with the NXT or RCX. [1]

As "getting started" parts, these parts are not a complete resource, answering all hardware and software questions. Instead, they are a starting point helping to begin building, programming, and operating NXT or RCX based physics models while collecting data.

All tools I present in this work have very high ceilings. In other words, teachers and students can take them to moon if they wish. This is good and bad. On the good side, it means that teachers probably have a solution to most complex investigation or engineering based physics projects. On the bad side, it means that there is the risk of getting lost in the technology, missing the point of a given investigation or engineering task. Using Albert Einstein's words of wisdom as a guide — "Everything should be made as simple as possible, but no simpler" — I present a part that introduces the hardware tools for exploring physics with robotics.

1.2 Comparing Hardware and Software Options

I do not present all of the options for using robotics in a physics classroom but rather the options that I have thoroughly explored in my own classrooms. As for hardware choices, Table 1.2.1 represents a comparison between the NXT and RCX. While features are important, I also understand that price and availability are also important. Teachers may be surprised to find a supply of kits that they can borrow. In addition, they can buying used. The 2009 was the last year that LEGO sold RCX. Teachers may find schools or individuals looking to transition from the RCX to the NXT, giving you a good deal on older RCX hardware. [1]

	RCX with ROBOLAB (RL) 2.9	NXT
Number of Motor ports	3	3
Number of Sensor ports	3	4
Rechargeable Battery System	No	Yes
IR Compatible	Yes	No
Bluetooth Compatible	No	Yes
Multiple Brick Communication	Yes	Yes
Motor speeds	100	100
Sounds	6 beeps	Infinite
Drive straight	No	Yes
On-board variables	64	100-1000
Display control	Numbers	text, images, numbers
Number of stored programs	5	Infinite
On-brick programming	No	Yes
Uses new and old sensors	(No)*	Yes
Hard-wire link to computer	No	Yes
3rd party sensors	Tough	Easy
On-board graph display	No	Yes

*Teachers can use the NXT Touch and Light sensors in RL 2.5.4 and all 4 **NXT** sensors + servo motor in RL 2.9

Table 1.2.1 Comparison between the NXT and RCX.

	Software for **NXT**	Software for RCX
Programming	MINDSTORMS NXT Software 1.0-2.0 Robolab 2.9	Robolab 2.5 - 2.9
Data logging	MINDSTORMS NXT Software 2.0 Robolab 2.9 Logger Pro 3	Robolab 2.5 - 2.9 Logger Pro 3

Table 1.2.2 The software choices.

1.3 NXT Motor and Sensors

Knowing how components work and how they connect with physics concepts will help facilitate and troubleshoot the activities. For instance, knowing that the distance sensor works via reflections of a sound wave will help to know from which surfaces teachers can and cannot obtain distance readings. Knowing that the light sensor can be operated with its LED on or off will help teachers determine if the light readings teachers have collected are from the ambient light of the room or from the reflected light of the sensor's LED. While I have chosen to focus on the NXT kit, the information can be applied to RCX's sensors and motors. A few differences are worth noting here:

- The RCX motor does not contain a rotation sensor but you can integrate one into your projects using LEGO's rotation sensor.
- LEGO does not make a distance sensor for the RCX.
- LEGO does not make a sound sensor for the RCX. [2]

1.3.1 NXT Interactive Servo Motor

Servomotors are a combination of an electric motor, position sensing device and a feedback circuit to control the motor. They are often used in radio-controlled devices such as model boats and planes. Pulse Width Modulation (PWM) controls servomotors where current is generated for certain intervals and at a rate of about 20 Hz. PWM is a fast switch, turning the motor on and off. If the motor is operated at a 50% power level then the PWM will cycle the motor on 50% of the time. If the motor is operated at 10% power then it will be cycled on 10% of the time and cycled off 90% of the time. PWM is a convenient way to enable software commands to control motor speed. [2]

The NXT motor is quite complex compared to the traditional 9V LEGO motor with the RCX kits. It has a higher ratio gear train and an optical encoder that reads the rotations of a slotted wheel. This encoder is accurate to the nearest whole degree. The gear train will make the motor slower than the traditional motor but produce more torque. Being a servomotor it is very useful for precision movements like robotic arms and positioning robots. It is very sturdy compared to the old motors. It is much less likely to be damaged while stalling and has no spindle that can snap off.

Concept connections:

-Velocity

-Acceleration

-Force

-Torque

-Frequency

-Electromagnetism

-Circuits

-Power

-Electric current

Project Ideas:

- Investigate simple parallel and series circuits with a motor and a 9-volt battery
- Add external gears to the motor and measure the torque produced
- Measure speed of a LEGO vehicle, predict times and distances

1.3.2 NXT Touch Sensor

The Touch sensor is a single pole, double throw switch behind a spring that toggles on and off after each press. It is referred to as a digital sensor because it only has two states.

The NXT touch sensor can be used for control programs such as a touch sensitive burglar alarm; a hand operated remote control; and starting and stopping motors or sensor readings. [3]

Concept:

-Newton's third Law

Connections:

-Simple Circuits

-Reaction times

Project Ideas:

- Test Newton's third law by using the touch sensor on a moving object vs. a fixed object. Which triggers the sensor?
- Use the touch sensor in a reaction time experiment. Program the NXT to turn on a light and start a timer. When the switch is activated, the timer stops.

- Using only a 9-volt battery, NXT to RCX cable, touch sensor and motor, build a circuit to turn on and off the motor with the touch sensor.

1.3.3 NXT Sound Sensor

Sound level sensors are used to represent the loudness (or amplitude) of a sound wave rather than its frequency. Frequency measurements require very high sampling rates while amplitude measurements do not. While the NXT does not have an adequate sampling rate to measure sound frequency, it can measure sound amplitude. The sound level sensor works by measuring changes in air pressure. The change in pressure on the diaphragm inside the sensor is used to measure the relative intensity of the sound wave in units of decibels (dB). The range of typical relative intensity scale is from the threshold of hearing (0 dB) to the threshold of pain (120 dB). The relative intensity scale is a logarithmic scale that serves to reduce the enormous range of sound intensities (measured in $Watts/m^2$, for example) between the threshold of hearing and the threshold of pain. By making the connection between relative intensity and intensity for students, you can help them understand that a sound sensor is really a sound wave energy sensor.[4]

The equation for intensity is:

Intensity = Power/Area

By replacing power with,

Power = Energy/Time

An equation for intensity can be rewritten as:

Intensity = Energy/Time x Area

Here, I am relating the measurements derived from a sound sensor to the energy of the sound wave. While my assertions represent general relationships and not specific quantities, they are useful for a student trying to understand what sound level measurements mean and what factors affect sound level. By explicitly bringing energy into the discussion about sound level readings, it helps students connect their sound measurements with other aspects of their physics study. [4]

This is especially important to consider when using the NXT sound sensor because the readings are not reported in decibels. Furthermore, sound sensor values vary according to the frequency of sound. When used in the dB mode, the sound level sensor filters its response to more closely match the frequency to sound level sensitivity curve of the human ear. As an approximation, however, sensor values of 0 to 100 correspond to relative intensity readings of 50 to 90 (dB).

Concept Connections:

-Relative Intensity vs. Intensity

-Relationship between Intensity, Power and Energy

-Law of Reflection

-Speed of sound

Project Ideas:

- Investigate the relationship between distance and sound level
- Explore sound wave diffraction, reflection, diffraction and conduction in various materials
- Map large scale interference patterns
- Test the effectiveness of a string and cup set-up to transmit sound

1.3.4 NXT Ultrasonic Sensor

Ultrasonic sensors determine the distance to a target by sending out sound waves at ultrasonic frequencies and listening for the returning echoes that are reflected from the target. The time (t) that it takes for the sound pulse to travel out to the object and then back to the sensor is the basis for obtaining the distance (d) measurement. Because this measured time is twice the value desired, the distance between the object and the sensor is:

$$d=\frac{t}{2}\cdot v$$

The LEGO ultrasonic sensor's operation and function is almost identical to popular motion detectors used in many physics labs. A key difference is that the sensor has a separate transmitter and receiver (left and right eye), and can therefore be used to measure objects at closer range. Ultrasonic sensors that use the same diaphragm need to build a "wait" into the system so that the transmission vibration can dampen before being read as it resonates with the echo pulse. A comparison between the performance of LEGO's ultrasonic sensor and other "motion detectors" such as one from Vernier Software and Technology would be an excellent activity. [5]

As stated in the product literature, the recommended range and accuracy of the sensor is 0 to 255cm +/- 3cm. If this level of performance is not being achieved, knowing the physics behind the sensor will help troubleshoot the situation. For example, reflection of sonic waves can be just as diffuse as light from uneven surfaces. Therefore, detecting small, non-flat, is difficult. These objects are acoustically opaque. Even larger flat objects can give you trouble if their surface is not normal to the incident beam. One more issue related to the performance of the sensor is the temperature of the room. Although, the impact of variations in classroom temperature in the range of +/-5 degrees is still within the expected error bars. It is a good challenge to give to students to have them figure out the range of temperature readings that will affect distance data reported by the sensor. [5]

For data logging tasks, any experiment requiring distance can use this sensor although the accuracy is likely to be less than that of the rotation sensor. However, in some investigation activities, the convenience of collecting linear distance without having to convert rotations into a linear distance is worth the sacrifice in accuracy.

For programming tasks, the distance sensor can be used for object detection and position control.

Concept Connections:

-Accuracy vs. Precision

-Sound frequency range - ultrasonic

-Law of Reflection

-Reflectance vs. absorption

-Speed of sound

Project Ideas:

- Investigate which shape objects can be used with this sensor.
- Investigate the range of angles for a flat plan that work with this sensor.
- Investigate the types of materials that will absorb sound vs. reflect sound.

- Determine the range of reliable measurements. Test hypothesis to determine the essential variables to maximize the range.

1.4 LEGO Building Primer

There are many books and web resources that cover LEGO building techniques but a few tips might be handy. In this section, I present ideas focused on the following:

- Building Durable Structures
- Motors and Gears
- Example LEGO Vehicles

The strength of a structure comes from reducing stresses. Linear stresses are:

Tension - the stretching of supports.

Compression - the squeezing of supports.

Pieces of LEGO are very strong in these directions. When pieces are joined together, the joint can be strengthened with overlapping beams. If a torque is applied to a structure, it experiences a twisting stress. This will reveal weaknesses in a LEGO structure unless it is strengthened with ties and struts. [6]

Teachers and students can reduce torque (i.e. the turning force) at any given point on a structure by reducing length to the pivot and/or sharing the weight along a number of beams. [6]

The use of gears offers physics students an excellent opportunity to explore many concepts from mathematical ratios to speed, force, torque, work, and energy.

1.5 Classroom Organization, Tips, and Techniques.

A significant challenge to overcome in LEGO activities is the organization of the equipment. This is particularly important if there are a number of classes sharing it. When thinking about organizing equipment, consider two options — keeping the gear in separate kits similar in design to the original MINDSTORMS kits or sorting all of your equipment into boxes or trays. For small classes, keeping the pieces in kits can work well. It gives students ownership over the maintenance and inventory of their own kit of parts. If teachers need to keep a tight inventory of parts, keeping organized and frequently inventoried kits is the way to go. If teacher have large classes, multiple classes, I recommend dividing all of the gear up into boxes or trays. Consider an organizational scheme that I use:

In a separate storage cabinet:

- Motors
- Sensors
- Wires
- Microcontrollers (NXT or RCX)

Seven trays of Lego pieces:

- Blocks
- Beams
- Plates
- Gears
- Wheels
- Axles
- Connectors, bushings and other small pieces [7]

Obviously, there are many other pieces but I use this organizational scheme to help students decide where to look for a part and to which tray to return a part. Consider this as a guiding principle: the easier it is for students to sort at the end of an activity, the more chance they put things away in their intended places. I tend to keep electronics and motors separate, locked away for safekeeping.

To facilitate the kind of movement common in robotics projects, I recommend an open style of room. This is a classroom where tables and cupboards are around the perimeter of the room and the center is left free for performance and investigation. Teacher might use the floor or have a few tables, depending on what students are doing.

To maximize the density of ideas, I present in a bulleted list format:

Classroom and kit specific tips:

- An alternative system for organizing kits is to reduce the number of elements per kit. For instance, if teacher anticipate that students will do several mechanics activities using the simple car designs, teacher can create a kit that contains those pieces. The smaller number of parts will be easy for students to manage and easy to inventory after the activities are done. Extra pieces and add-on pieces can be kept as a whole class resource.

- Kits with limited pieces can also help students focus their design ideas, helping them achieve design goals quicker.

- If students are using the designs found in this work or other books, teacher must build at least one classroom model that students can reference as they construct their own models.

- Teacher can allow students to personalize their products. It may appear unproductive but it encourages ownership and helps students distinguish their project from others.

- If teacher already have lines on the floor such as tiles, use them to mark starts and finishes.

- Tape on the floor is a very useful resource for many robotics activities. Tape stuck on a tiled floor can last through a lot of wear and tear but check with custodial staff and use a tape that does not interfere with the work. I recommend "painters" tape. This is a type of masking tape (often blue in color) that does not leave a gummy residue when it is pealed off the floor. Tape left on the floor for a long time can be scrapped up with a razor blade.

- Batteries, batteries, batteries! Teacher can create a system that works well students to help manage battery charging. If teacher is using rechargeable AA batteries, set up a shelf or cabinet with separate bins for depleted and charged batteries. Write a date on charged batteries.

- AC Power.

- Downloading firmware onto the RCX can be a pain. The RCX communicates with the computer via an infrared tower. Be aware of interference from other infrared sources such as classroom lights and sunlight. [7]

Data logging tips

- Check sensors to see that they meet your expectations by doing some initial readings.

- Explain typical graphs of sensor readings before students produce them. Often, students are put off by the spikes in a graph rather than the trend or shape. Collecting 25, 50 and 100 readings per second produces "noise". Encourage your students to look for trends within the noise.

Team building and group processing tips

- Robotics projects work well as a group project. There are many tasks to complete; everyone in a group can make valuable contributions. Depending on what works best for students, teacher have the option of defining student roles or encouraging the group to define group roles themselves. To encourage skill building, I recommend that students change their roles throughout the semester. Building, programming, data logging, and analysis work help students build a diversity of valuable science lab skills.

- Always leave a window before and after activities to brainstorm and review. For open style designs and investigations, students want a balance between freedom to choose and some guidance. [8]

- Having students share what they did to solve a problem is a nonthreatening way for other students to learn and still feel they own their solution.

2. Software

2.1 LEGO® MINDSTORMS® Education NXT Software 2.0

What follows is a brief introduction to the LEGO MINDSTORMS Education NXT Software 2.0. MINDSTORMS software is a graphics based program built on the industry standard program Lab VIEW™ from National Instruments (www.ni.com). What sets this program apart from other software available to program the NXT are the embedded objects called "blocks". When a block is chosen from the menu (called a palette) and active on the work page, a configuration window appears at the bottom of the page with settings that can be altered. The combination of easy to interpret graphical blocks and a configuration window allows students and teachers to start programming with little to no prior experience. [9]

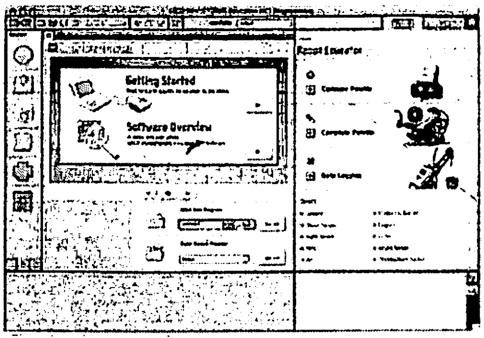


Figure 2.1.1 Opening screen for LEGO MINDSTORMS Education NXT Software 2.0.

Most of the programs write will require multiple blocks. Blocks are linked along a data wire that looks like an extendable LEGO beam, with positions made available as blocks are moved. This makes programs very easy to write and requires few objects because of the extensive configurations built into each block. Fairly complex programs can be written with only a few icons.

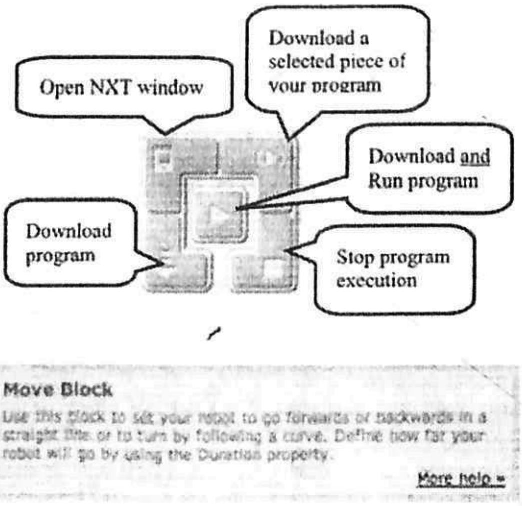
Program blocks are organized into three palettes — the Common palette, Complete palette, and Custom palette. The common and complete palettes are suited for beginner and intermediate levels of programming. The Common palette includes the basic blocks used in robotics projects:

- Outputs (motor, sound and display)
- Inputs (wait for sensor input or time)
- Processors (loops, switches, or forks)

- Record/Play (allows recording of motor actions and replaying when required)

If teacher program requires using sensor values to control outputs or more advanced features such as Bluetooth, Variables, and Data logging , switch to the Complete palette.

The Custom palette is available for a special group of programs called “My Blocks”. “My Blocks” can be created from a configuration of regular blocks by selecting a group of blocks and clicking on the "Create My Block" tool at the top of the application window. [10]



Use this block to set your robot to go forwards or backwards in a straight line or to turn by following a curve. Define how far your robot will go by using the Duration property.

Figure 2.1.2 Controller buttons and the help window.

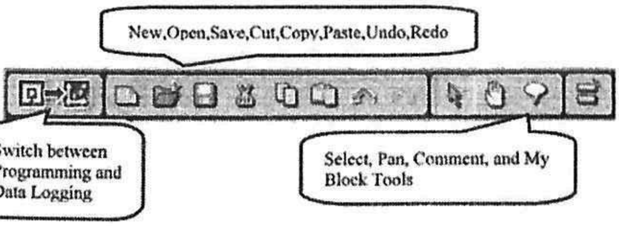
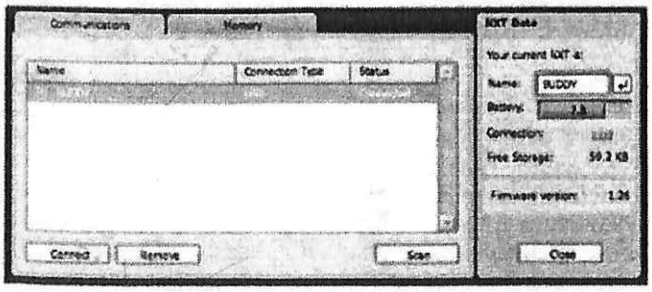


Figure 2.1.3 Tools available at the top of the application window.



Your current NXT is:

Name: BUDDY

Free Storage: 50.2 KB

Firmware version: 1.26

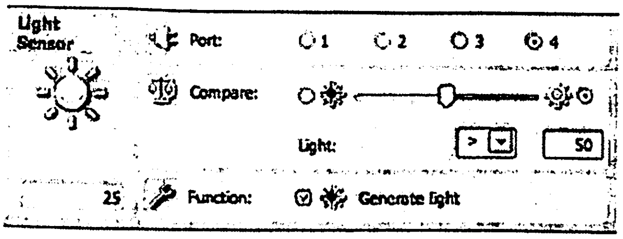
Figure 2.1.4 The NXT window button on the controller is used to manage device.

2.1.1 Using Sensors

In the Complete palette is a sub-palette called Sensor and a list of supported sensors are shown when it is accessed. If teacher drag a sensor out of a palette and into the programming area, he will see a display area for the sensor in the lower left hand corner of the screen. Teacher can see the current value of the sensor in this display area if the NXT is on and connected (Figure 2.1.5). This can be very useful for checking sensor values or even monitoring an event using the computer as a digital display for sensor connected to the NXT. [11]

To use the NXT screen as a display for sensor readings, teacher can add the "display" icon from the Action sub-palette. An example program is shown in Figure 2.1.6. One thing to notice in the example program from Figure 2.1.6 is the flow of data. The value of a sensor can be sent to different parts of a program by wiring sensor values to other icons in program.

When used in conjunction with icons from the Data palette, sensor values can be wired into logic statements, math functions, value comparisons, range determinations, and stored in variables. In the Flow sub-palette, sensors are built into wait statements, while loops, and switches (if/then statements).



Light Sensor

25

Port: ○ 1 ○ 2 ○ 3 ● 4

Compare: ○ ●

Light: > 50

Function: ☑ Generate light

Figure 2.1.5 Sensor display

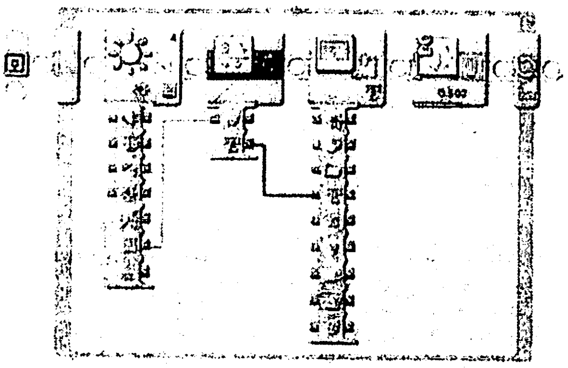


Figure 2.1.6 The program used to send values to the NXT screen.

2.1.2 Data logging

One major addition to the MINDSTORMS software in the 2.0 version is Data Logging. Data Logging allows to upload sensor data from NXT to the computer where it can be viewed as a table or a graph. This feature of the software can be accessed in two ways. One way is to click on the "Switch to NXT Data Logging" button in the upper left corner of the application window. The other is to use a data logging block in a program. The data logging block is found in the "Advanced" category of the Complete palette.

After click on the "Switch to NXT Data Logging" button, teacher will see a window titled, "LEGO MINDSTORMS Education NXT Data Logging". In this window, teacher can either start a new project or open a saved project. If click on the "Go" button to start a new experiment, teacher can see an experiment configuration window. Use this window to tell the system what sensors will use, where they are located, how fast to collect data and the experiment duration. Once click OK, teacher can see a blank graph and is ready to go. Connect sensors, turn on NXT, and start experiment by pressing the "play" button on the data logging controller (right and side of the screen). If teacher need to change parameters from the experiment configuration window during an experiment, he can access this window again by clicking on the "Configure Experiment" button on the top-left side of your graph. [12]

At this point, teacher can interact with the program like most data logging software applications. Teacher can collect data, do a basic analysis, and save your data. When teacher save data, it is saved as "log" file. The log file is simply a text file. If teacher need to do additional analysis of the data, he can import the log file into a spreadsheet. If teacher have difficulty importing a file into a spreadsheet, he can open it up in a text editor, delete everything that is not data and resave it as a text file. This will leave you with a "tab delineated" data file that can be readily imported into most spreadsheet applications.

Data analysis can be done within the data logging window.

Capabilities include:

- Multiple data sets plotted on one graph
- Change of scale for all y axis variables
- Prediction tools (linear function and free drawing)

- Min, max, and mean of a selected region
- Linear fit of selected region

2.2 ROBOLAB™ 2.9

Originally developed in 1998, ROBOLAB was designed as a programming and data logging environment for the RCX. It was the result of a partnership between Tufts University's Center for Engineering Education and Outreach (CEEO), National Instruments, and LEGO Education. In 2006, ROBOLAB was updated to work with both the RCX and the NXT. In 2006, MINDSTORMS NXT Education Software was also introduced with the idea of replacing ROBOLAB at the primary and middle school levels. As I presented in our previous section, however, MINDSTORMS software is also an excellent tool for high school physics instruction. What it lacks, though, are advanced data analysis and customization features needed by upper high school and college physics instructors. [12]

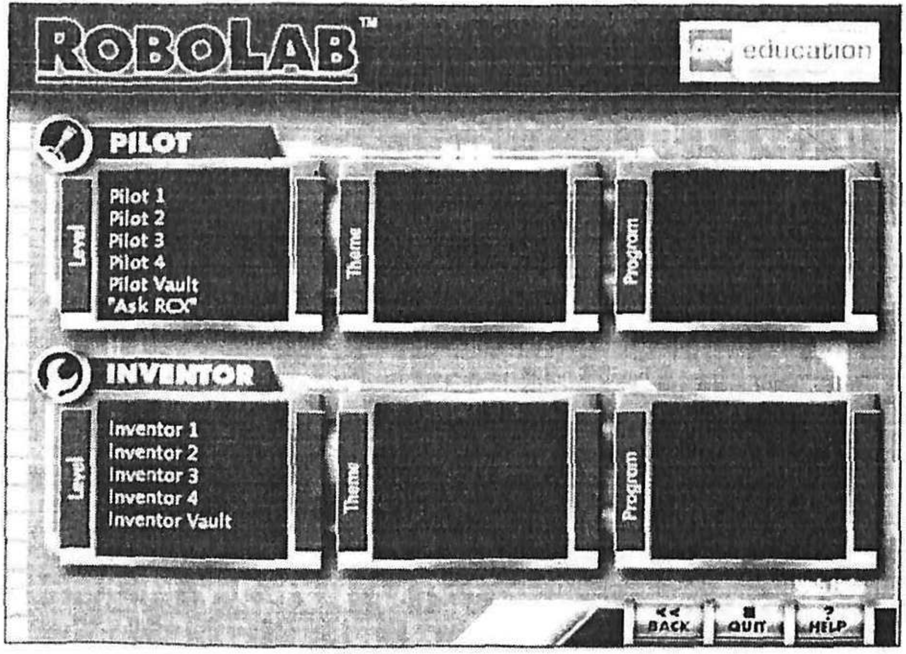


Figure 2.2.1 ROBOLAB's Programmer environment.

Like the MINDSTORMS software, ROBOLAB is also based on LabVIEW. One key difference between these software packages is that ROBOLAB allows the user to access LabVIEW tools such as custom front panels. The Tufts CEEO and National Instruments are currently developing a new product called LabVIEW for High School. This product will build upon the success of ROBOLAB and give secondary teachers and students more access to the powerful LabVIEW package. I am getting ahead of ourselves here but felt it worth noting the relationship between ROBOLAB and the future LabVIEW for High School. The MINDSTORMS software was designed to succeed ROBOLAB in the primary and middle school market and LabVIEW for High School will succeed ROBOLAB in the high school market. ROBOLAB, however, will still live on. Once LabVIEW for High School is released, ROBOLAB will be made available as an optional download. [13]

As stated earlier, this section on ROBOLAB provides a brief overview of the ROBOLAB programming language and its data logging capabilities. When teacher launch ROBLAB, will see three choices: Administrator, Programmer and Investigator. Administrator allow to manage RCX or NXT by changing communication ports, updating firmware, changing both software and hardware preferences, and checking battery level. Like MINDSTORMS software, ROBOLAB provides both programming and data logging environments. These environments are organized into three areas: Pilot, Inventor, and Investigator. Pilot, and Inventor are found after pressing the "Programmer" button on the opening screen. [14]

2.2.1 Programmer: Pilot

Pilot is a very fast and easy to use programming environment. It uses icons that are already placed together as a program. To change program, click on an icon to choose from a few options. The default pilot programs make it convenient for the user to program the NXT or RCX with simple behaviors. Many physics activities can be done with Pilot level programming. [15]

2.2.2 Programmer: Inventor

In this environment, program icons are "wired" together to build a program. It is an extremely flexible and customizable environment. There are four programming levels within Inventor. Default programming structures that can be changed or modified by the user are found in levels 1 and 2. Levels 3 and 4 start with a blank programming window and users must write their entire program from icons in the "Functions palette". This palette provides a selection of programming elements such as sensor inputs, motor and lamp outputs, program variables, loops and other programming structures.

The main difference between Inventor levels is the number of icons available in a palette. Inventor level 4 offers many options but requires more time to learn how to take advantage of the available programming power. If teacher anticipate that students will be creating custom programs and are interested in pushing hardware and software to the limits then taking the time to learn how to program in Inventor level 4 is well worth the effort. One guide to help choose which level to use is the consideration of programming speed and complexity. The higher Inventor and Pilot levels require more time but teachers will have access to more options. In my experience with ROBOLAB, I tend to use the Pilot levels or Inventor 4. By starting with Inventor 4, teacher know that have access to all the features that teacher would ever need. For instance, access to third party sensors is only available in Inventor 4. [16]

2.2.3 Third Party Sensors

If teacher wish to use sensors from third party sensors, teacher will be required to write programs in Inventor level 4. If system is updated to version 2.9.4c, teacher will have icons in "User Libraries" folder for sensors from Vernier, HiTechnic, and Mindsensors.

2.2.4 Data Logging Overview: Investigator

The Investigator programming mode includes features from both Pilot and Inventor levels along with the added feature of data logging and advanced data analysis. There are options for five programming levels within the Investigator. Levels 1-3 provide the user with a default data logging program. This program could be used on a single motor robot when you need to collect data as the vehicle is driving. Changes are made to programs by clicking on icons and picking new ones. Collecting data from third party sensors is only possible in Investigator Level 5. [17]

Investigator helps manage projects through a navigation window on the left side of the screen. This window provides access to the Program Area, Upload Area, View and Compare Area, and Compute Tools. [17]

Example data logging program.

Follow these steps to collect and graph data with RCX or NXT:

1. Open up a new Investigator project. Choose Program Level 1.

2. Connect desired sensors. Set the desired data collection interval and number of samples.

3. Download the program to your RCX or NXT by either clicking on the single white arrow or the double arrow. The double arrow will run the program in "direct mode",

which graphs the data as it is being collected. If teacher use the single download arrow, you must run the program on the RCX or NXT to collect data.

4. Once you have collected data, click on the Upload Area in the Navigation Window.

5. Click on the white arrow in the upload arrow to transfer the data from the RCX or NXT to your computer.

6. To add Data Sets to your project, click on the "+" in the upload area and repeat steps 1-5.

The View and Compare area allow to view uploaded data sets and obtain statistical information. Data can be viewed in different representations such as line, bar, and table form. Several statistical tools are available including measurements for minima, maxima, means, standard deviation, slopes, and areas.

The compute tools area provides additional options for data analysis. This area is used when calculus and other advanced functions are required. This option has five levels. Compute tools levels 1-3 include analysis options for data transformations (level 1), changing the x-axis from time to another data set (level 2), statistics to more complex operations such as taking derivatives and integrals (level 3), and writing your own analysis program using LabVIEW tools. [18]

2.3 ROBOLAB Front Panels

In a ROBOLAB program there are two windows for programming. One is the Block Diagram window where all ROBOLAB programs are built and the other is that mysterious black window called the "Front Panel". In most programs that window is blank and is not used. However if teacher want to be interactive with the user, this programming window is invaluable. [19]

Creating front panels is advance, using front panels is not! Using front panels with students requires very little programming knowledge. In fact, very little understanding of the operation of the software is required. Simply load and run the front panel. This means student can maximize the time spent data logging, observing and analyzing information in science project.

2.3.1 Basic principles of LabVIEW programming

LabVIEW is an industry standard programming language with software, training, and support available at www.ni.com. Professional versions of the software are expensive but student editions are available at reduced prices. A toolkit for MINDSTORMS NXT programming is available from www.ni.com/mindstorms. ROBOLAB, however, has LabVIEW as a part of its package. The front panel and block diagram use graphical language programming. The block diagram, teachers are probably familiar with as a ROBOLAB programmer. This is where the program icons go. The front panel is the interface used by the operator. The programming elements in a front panel are called "controls" (inputs) and "indicators" (meters, text displays, and graphs). These objects are placed on the screen using the controls palette. This is different from the functions palette on the block diagram and only becomes available if you are working on a front panel window. [20]

In the following section, I explain how to create the front panel. This panel is designed to be used with a single motor car that has an angle sensor. NXT motors have a built in angle sensor. RCX systems will need to mount a separate rotation sensor. The front panel has two distinct functions. First, it allows for student input. They can change the power level of the motor and travel time for the car. It also allows students to input the diameter of the wheel attached to the motor. This allows the program to correctly scale the distance graph, changing rotation data into linear distance data. The 2nd function of the front panel is to display data that comes back from the car after it is has been driven.

I divide our example into five steps.

Step 1: The "Download" Program

Start ROBOLAB and navigate to Inventor 4. In block diagram window, write a program to initialize and begin data logging a rotation sensor. Add a motor to drive the car forward at an inputted power level. Enable user input by creating a control (right click on the wiring point of the motor and choose "Control"). The length of time for motion can also be inputted (right click on the wiring point of the "wait for time" icon and choose "Control"). Stop data logging and stop motor.

Step 2: Creating the Front Panel Objects

For the second part of front panel programming, a higher level of Inventor is required. This is the level that is available through Investigator and is called G CODE. Do not switch to Investigator, however. It can be accessed directly from your Inventor program by:

1. Choose "Change Inventor level" in the Projects Menu.

2. Click on the wrench icon to toggle levels and choose either "Programming Level 5" or "Compute Tools 5".

This level of programming allows programming on the Front Panel and this is the place to work on for Step 2. If teacher do not see your front panel, teacher can access it by choosing Window -> Show Front Panel. A keyboard short cut is handy to know because teacher will be switching back and forth between windows often. Use ctrl-E (PC) to make the switch between the front panel and block diagram windows.

Now teacher can adjust own front panel. When student created the two controls in program from Step 1, they showed up on front panels as numeric boxes. If teacher right-click on the box, teacher can use the "replace" option to change them to the slider and meter. [20]

To add in the text box for the wheel diameter, drag a numeric box in from the "Classic Numeric" section of the controls palette. To add the Download and Upload buttons, drag them from "The Classic Boolean" section of the palette. Next, add graphs by dragging three "XY Graphs" from the "Classic Graph" section of the controls palette.

All of these controls and indicators can be resized, relabeled, and formatted by using the various pointers in the Tools Palette and by right clicking on the objects tinkering with the choices available in the context menus. One extremely useful context menu option is "Properties" because teacher can change a graph's data range, accuracy, labels and axes scale.

Step 3: Setting up Events

The next step involves separating the download program from the upload and analysis (GCODE) program. These two separate tasks are called events and they are controlled by the "Download" and "Upload" buttons in the front panel. In the download event, students send their motor power and time commands to the vehicle. In the upload event, students tell the NXT or RCX to send its data to the computer so it can be displayed in the three graphs. To establish the download and upload events, go back to the block diagram window.

Teacher will notice that block diagram has a few new objects in the window. Each one represents modifiers matching the controls and indicators from the front panel. Also, since teacher changed your Inventor level, the block diagram functions palette for Programming Level 5 now contains options for "Data Logging And Motors", which is the traditional palette for Inventor 4, and a GCODE palette where teacher will obtain the data analysis and LabVIEW programming structures necessary for this step.

Click on the G CODE palette to define your download and upload events. To do this, you will need to find the "event structure" in the GCODE palette. Click on it and drag it arouund ROBOLAB code.

These event structures are powerful because they wait for an input from the user. In this case, the input is a click on the "Download Now" button. To include the "Download Now" button, you need to drag the "Download Now" Boolean input (the T/F) into the event structure. Right-click on the "Timeout" label at the top of the event structure. Choose "Edit Events Handled by This Case". This brings up an "Edit Events" window. Choose "Download Now" and "Value Change". This means that when the "Download" button is toggled on and off the program in event structure will be downloaded to the NXT. Finally, wire the "Download Now" Boolean object to the edge of the event. [21]

Step 4: The UPLOAD program

First, add a second "Event Case" to the existing event structure by "right-clicking" on the Structure boundary. Choose "Add Event Case". Drag your "Upload Now" Boolean object into the event. Repeat the procedure from the previous step to edit events. Choose "Upload Now" and "Value Change". Click OK and wire "Upload Now" Boolean object to the edge of the Structure.

Teacher now have two cases in event structure. Teacher can switch between these by clicking on the arrows in the case label at the top of the structure.

Step 5: Keep the Front Panel's Program Running Until the "Stop" is Pressed

This final step is not essential. It is more of a convenience. In this step, teacher need to add a "while loop" around entire case structure. Next, create a "Stop" button in your front panel, return to the block diagram and drag it's Boolean identifier into the new case. Add another case to the event structure and choose the Stop button as the case specifier. Drag the Stop button's Boolean identifier into the event structure and wire a boolean T/F into the stop sign of the while loop. The T/F icon is found in the GCODE palette. When the program is run, the loop will keep the front panel running until a value of "true" is passed to the loop's stop sign. This happens when the "Stop" button is pressed. [27]

That's It! The "Download" and "Upload" programs are now hidden while the user interacts with the front panel. In other words, the user does not need to know how these programs operate in order to use the front panel to do some very powerful physics projects!

2.4 Logger Pro®

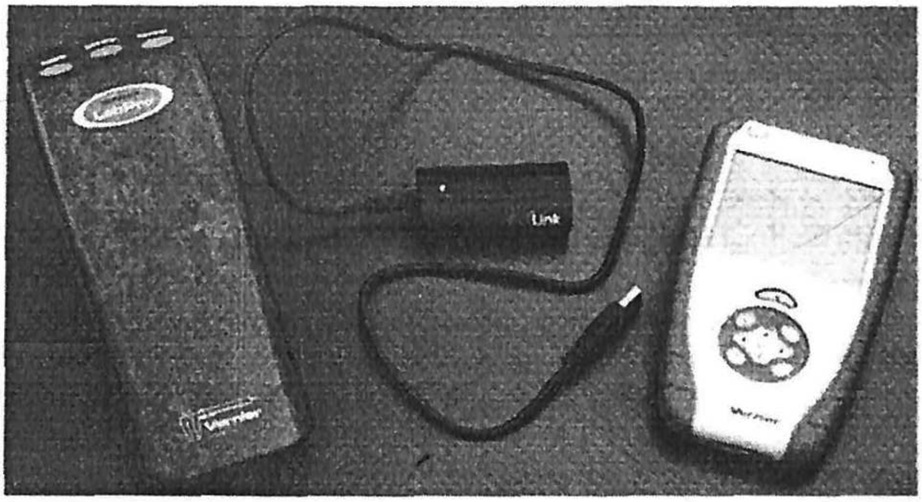


Figure 2.4.1. When using Logger Pro, teacher need to connect sensors to Vernier interfaces such as the LabPro®, Go!™Link, or LabQuest.

Vernier Software and Technology has been making data logging tools for teachers since the 1970s. Starting in 2006, Vernier, LEGO, National Instruments, and the Tufts Center for Engineering Education and Outreach (CEEO) formed a partnership in an effort to integrate the robotics and data logging technologies offered by the four organizations. In this section, I present to teacher a guide for using Vernier's Logger Pro software in robotics projects. One key difference between data logging via MINDSTORMS or ROBOLAB and Logger Pro is that the NXT is not used as the interface between the sensor and the computer. Teacher will need to connect the sensor to the computer through an interface manufactured by Vernier (Figure 2.4.1). If teacher are using sensors from other companies such as Pasco, Fourier, or Onset, use interfaces that are compatible with their software. While I do not present any additional information specific to software from these companies, it is likely that the features I highlight here are easy to find in their data logging programs. Additionally, I chose to include Logger Pro in the work because it is a highly refined product with easy to use data collection and analysis features for beginner and advanced users. [22]

To start using Logger Pro, teacher can either start from scratch by opening the program itself or by double clicking on a previously made file. Teacher can also access previously made files by using the "File -> Open" menu item. If teacher have a sensor connected to the computer directly or through a Vernier interface, it will be automatically identified and teacher can start collecting data. [23].

Once teacher have connected to desired sensor, teacher can confirm that students are ready to collect data by looking at the program's "collect" button. It will be green when the program is ready to collect data. If teacher do not change any other settings, the program will use a default data collection rate and duration, which is set for each sensor. To meet the needs of investigation, teacher will want to click on the data collection settings button in the toolbar or choose the Experiment Data Collection menu option and make adjustments. [23]

3. Motion

3.1 Going the Distance

Age Group: 14+

Essential Question: Can you tell a robot how long to travel an exact distance? Recommended Time: 45 to 90 minutes.

Materials: NXT or RCX Kit, meter stick or measuring tape, LEGO Figures or other miniature characters

Activity Overview: In this activity, students will be given a set distance between two lines of tape. On one line, students will place their LEGO vehicle. On the second line, a row of LEGO or other miniature characters will stand. The goal is to predict the exact time to program the LEGO vehicle such that it will travel and stop as close as possible to the miniature character without touching it. This is not a "trial and error" process. Students will complete a series of measurements and organize their data into a model (i.e. graph, data table, and/or equation) that allows them to accurately predict the time required to travel the challenge distance. [24]

Learning Objectives:

By the end of this activity, students will be able to:

1. Create a data table, graph, and/or an equation based mathematical model of an object's motion.
2. Use a mathematical model to predict the motion of an object
3. Test a prediction with an experiment
4. Refine their models based on new experimental evidence

Pre-Activity Discussion Questions:

1. In science or engineering, what is a model?
2. What are some examples where table, graphs, and equations are used as models?

Activity Instructions:

1. Create a basic LEGO vehicle that drives straight or use one built for a previous activity. For the purposes of this activity, "straight" means that your vehicle can drive approximately 3 meters while moving left/right less than 0.2 meters.

2. Using Mindstorms or Robolab software, program vehicle to drive forward for a certain amount of time. Observe how far your vehicle moves.

3. Consider the challenge posed by your instructor - "Figure out the necessary measurements and process by which you will organize those measurements (via equations, graphs, data tables, etc.) to predict the time robot will travel any given distance." In other words, create a model that allow to predict the time of travel for any distance vehicle moves.

4. Once students have figured out model, test prediction with a series of experiments.

5. Refine model as necessary so students can get as close as possible to the distance defined in the final "Going the Distance" challenge.

6. When instructor has created the final "Going the Distance" challenge, do the necessary measurements to predict the time of travel

7. Observe how close student come to the line.

Student Observations and Analysis:

Data

Time of Travel	Distance Traveled	Notes

Draw a graph on graph paper of Distance Traveled versus Time.

Reflection Questions:

1. How close did your vehicle get to the challenge distance?

2. When you organized your measurements for this activity, you created a model that represents the motion of your vehicle. Your model may have been a data table, graph, and/or an equation. What type of model did you use to represent the motion of your vehicle and how well did it work to help you make accurate predictions?

3. If you could do this activity over again, explain what changes you would make (if any) to your LEGO vehicle.

4. If you could do this activity over again, explain what changes you would make to collecting and organizing your data.

5. If you could do this activity over again, explain what changes you would make to the process you used to make your predictions.

6. Think about the steps you followed during this activity. Do scientists and engineers perform similar steps in their work? Think of an example and explain.

7. For your car, can you give a general rule for how far this car goes per second, (speed)? Use this answer to determine the following:

a. Where would the car be after 10 s?

b. How long would this car take to travel 1 m?

Notes and Extensions:

1. While the original design of this activity ends after one challenge distance, consider conducting three, allowing the students to continue refining their models.

2. This activity works very well as one of the introductory activities in a physics curriculum. It lends itself well to follow-up discussions about models - their creation, use, and refinement. As a kinematics activity, it allows students to explore a prediction activity based on their understanding of motion concepts.

3.2 An Investigation of NXT Motor Speed

Age group: 15+

Essential Questions: How exact is the motion of an NXT? Is power level 100, one hundred times faster than power level 1?

Recommended Time: 40 - 50 minutes.

Materials: NXT LEGO kits, NXT data logging software

Activity Overview: To investigate the NXT motor speed versus power level, I could measure distance traveled for one second, for each power level and convert to speed. Gather the data for all power levels and look for a relationship. This would be an arduous task that could be relieved by sharing the job across the class. [25]

For a more independent activity, why not use the power of programming and rotation sensor data logging and run the motors at all speeds for a constant length of time each.

Learning objectives:

1. Design and perform controlled investigations.

2. Refine investigations after evaluating variations and inconsistencies.

3. Analyzing linear mathematical relationships between variables and determine gradient.

4. Use mathematical ratios to verify physical laws.

Building Ideas:

Any NXT car, one motor is sufficient.

Activity Instructions:

1. Need to increment the power levels from 1 to 100 and run the car for equal length times for each power level.

2. The motor encoder needs to be data logged but not just the total angle, instead calculate the distance moved for each power level. For example run the car through all power levels for a total of 10 seconds. For 100 power levels this means 0.1 s per level. To get a good reading for speed the angle position on the encoder needs to be sampled often e.g. every 0.01s (10 times per level).

3. Use variables or containers to store the angle difference (displacement angle) and the power level so these can be logged. Teacher will need more than one variable to read angle before and after each level. The difference between these called the displacement angle can then be found.

4. Teacher must still initialize the data logging of the motor encoder and variables of displacement angle and power level. The data logging sampling rate for variables needs to be only once per level e.g. 0.1s.

5. Download the program and run the car on an obstacle free flat course.

6. Upload the data.

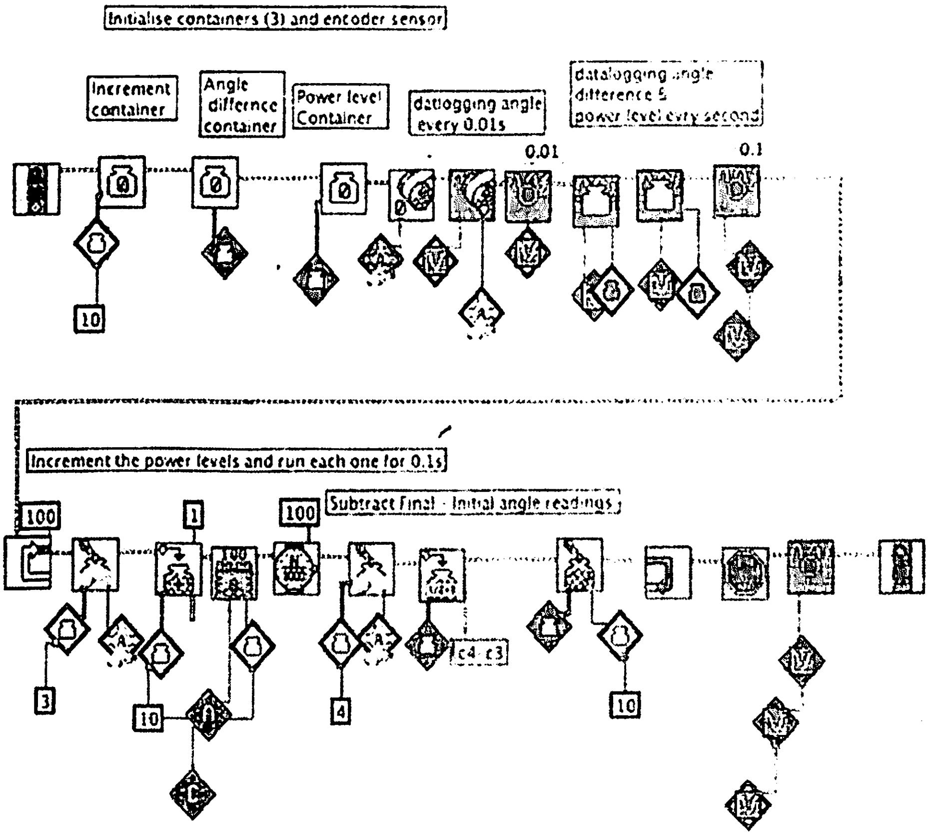


Figure 3.2.1 Sample Robolab program for NXT Motor Speed

Student Observations and Analysis:

1. In your graphical analysis program, you need power level changes on the X-axis and angle distance on the Y-axis.
2. What was the general trend of your data?
3. If the graph was linear, determine the slope.
4. What does this slope represent and how can you use it to determine speed (cm/s) per power level?

Analysis Procedures using ROBOLAB INVESTIGATOR:

1. On the UPLOAD area, three data sets should be obtained:

a. Power levels versus Time.

b. Motor Encoder absolute angle readings versus time.

c. Displacement Angle versus time.

2. To View Displacement Angle versus Power level:

a. On COMPUTE tools 2.

b. Add the y-axis data of the power level to the x-axis and the y-axis data of the angle displacement to y-axis.

c. Store this graph in a new container. Examine the shape of the graph.

3. If the relationship is approx. linear (which it should be!) find the slope using the VIEW area and Measure window and slope tool.

4. The slope gives the value of degrees of rotation in 0.1s intervals per unit power level. Convert this to rotations/s and also revolutions/s.

5. From the wheel size determine what is the speed factor per unit power level.

6. Now write a formula to convert power level to speed. [15]

Reflection Questions:

1. Are the NXT motors linear within acceptable error?

2. Explain in a few lines what this means in terms of distance traveled at different power levels.

3. Explain how you would program an NXT to go 1 meter at 20 cm/s.

3.3 Testing Speed versus Acceleration of Drag Cars.

Age Group: 12+

Essential Question: In a Drag car race what is more important; high speed or high acceleration?

Recommended Time: 40 - 50 minutes.

Materials: LEGO Kits (RCX with motor and rotation sensor or NXT with motor/encoder), ROBOLAB.

Activity Overview: This activity allow to directly measure distance, speed and acceleration of a car, by displaying graphs on the front panel of a ROBOLAB program. The student inputs the power level, time, and diameter of the wheels, downloads the program, runs the car and is able to upload the data collected back to the computer for analysis. [26]

Learning Objectives:

Compare various factors that may improve speed and acceleration including power, time of travel, gear ratio and wheel size.

Building Ideas:

A simple single motor, geared LEGO Car (RCX or NXT) with a rotation sensor on the front wheel axle.

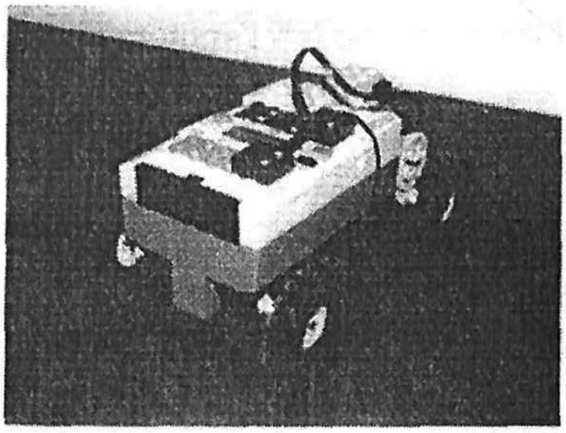


Figure 3.3.1 Simple car

Programming Ideas:

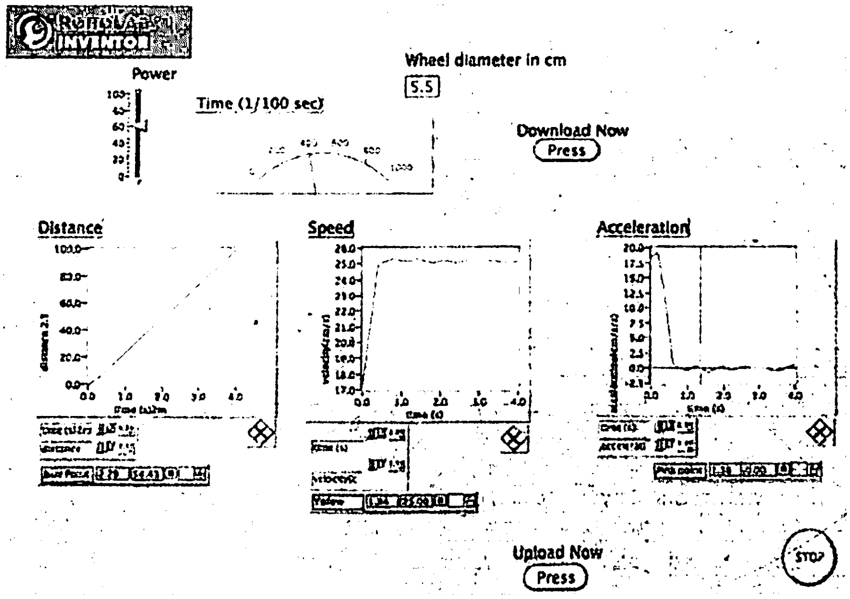


Figure 3.3.2 ROBOLAB Front panel for the activity: Testing Speed and Acceleration of Drag Cars.

Graphs may be obtained from angle sensor data using Mindstorms 2.0 and ROBOLAB Investigator but for the best comparisons I recommend using a custom front panel run in ROBOLAB. [27]

Activity Instructions:

1. Use the Front Panel of the program "accelerations.vi" to input time, power level and rotation wheel's diameter for the download program.

2. Put the car in front of the tower. Click on white arrow to run and then Press DOWNLOAD Now.

3. Take the car and run it across the room.

4. Put the car in front of the tower. Click on the white arrow (if necessary) and then press UPLOAD Now.

5. Determine the total distance, maximum speed and acceleration. You can use the cross hair pointer and read the y values in the window below the graph.

6. Repeat using a different time and power level. Record results.

7. Try changing the gears around.

8. Try different size wheels on front or back (remember to change the input)

Student Observations and Analysis:

Changes	Time	Power Level	Distance	Max. Velocity	Max. Acceleration
a. Low ratio geared car	1. 2.	1. 2.	1. 2.	1. 2.	1. 2.
b. High ratio geared car	1. 2.	1. 2.	1. 2.	1. 2.	1. 2.
c. Different wheels	1. 2.	1. 2.	1. 2.	1. 2.	1. 2.

Reflection Questions:

1. Does changing time affect distance, speed and acceleration?

2. Does changing power affect distance, speed and acceleration?

3. What gear ratio do you need for high speed?

4. What gear ratio do you need for high acceleration?

5. What affect does wheel size and type of wheel have on the speed and acceleration?

6. Why does a car need to change gears as it speeds up?

7. For a better drag car what is required?

Notes and Extensions:

1. It is important the students test various gear combinations. It is easy to swap the 8 tooth and 24 tooth gears around on the single RCX car.

2. For different wheels, students must alter the wheels diameter window to the correct value for the wheel connected to the rotation sensor only.

3. Further discussion and challenges relate to finding other ways to increase the cars velocity.

4. Make own Drag Car according to the optimum results of factors students have tested.

3.4 Projectile Motion

Age group: 14+

Essential Questions: When a projectile is launched straight up from a car moving along a straight line at constant speed, where does the projectile land?

Recommended Time: 40-50 minutes.

Materials: NXT or RCX Kit Launcher, motor for Launcher, data logging software

Activity Overview: This activity can be used to introduce the concept of projectile motion in the high school physics curriculum.

A projectile is any object, which once projected continues in motion by its own inertia and is influenced only by the downward force of gravity. [28]

There are a variety of examples of projectiles where horizontal and vertical motion occur:

- An object dropped from a moving object e.g. an airplane
- An object thrown from a cliff.
- An object thrown upwards at an angle.

Students have an opportunity to investigate the principle of constant horizontal velocity of a projectile through building a model car that will launch an object vertically as it moves.

Learning Objectives:

1. Learn about examples of projectile motion
2. Understand vertical and horizontal components of motion
3. Analyze projectile's path by considering the horizontal and vertical components

Building Ideas:

1. Build a simple sturdy LEGO/NXT car
2. Add to the car a simple launcher, such as the one shown using a Spring- Loaded Rubber tipped dart LEGO piece (see Figure 3.4.1).

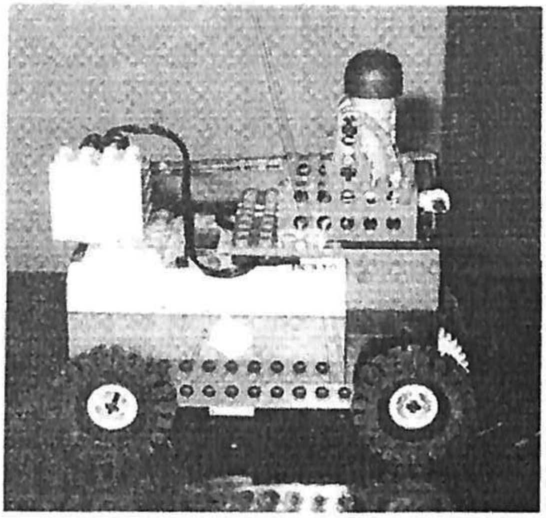


Figure 3.4.1 LEGO model with launcher

Activity instructions:

1. Program the car to move with constant velocity (use a constant power level).

2. Program the motor on the launcher to start 4 seconds after the car moves and run for 1 second.

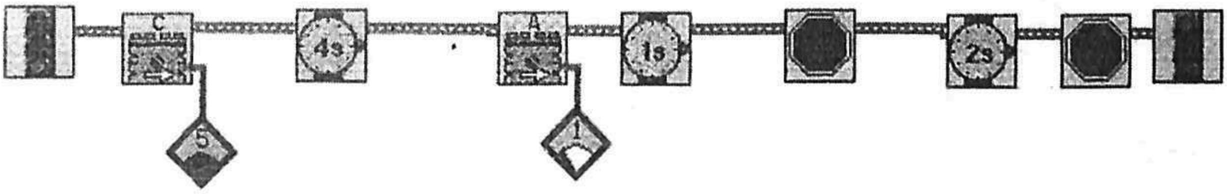


Figure 3.4.2: Sample ROBOLAB program in Inventor 3.

3. Place the object for launching.

4. Test the model launcher without running the program:

- Manually launch the projectile and test that it lands back on the launcher.

- If not adjust it for a vertical flight.

5. Start the program and observe the landing as the car moves.

6. Try a different speed for the car and repeat the investigation.

Student Observations and Analysis:

1. Where does the projectile land when it is launched vertically from the moving car?
2. Was it different to the launch from the stationary car?
3. Does higher speed have any effect on its landing?

Reflection Questions:

1. What factors affected the motion of the projectile after it left the car?
2. Can you be sure the car moved at a constant velocity? How can you test this?
3. A car is moving along a straight line at a constant speed of 25 m/s. It launches a projectile straight up. What is the value of the horizontal velocity component of the projectile at the highest point? Neglect air resistance. Explain your answer.
4. Which is true:

Ideally, a projectile's horizontal velocity component:

a. Does not change.

b. Changes most rapidly near the bottom of its trajectory.

c. Changes at a constant rate.

d. Changes most rapidly near the top of its trajectory?

Explain your answer!

5. A car is moving with acceleration along a straight line. It launches a projectile straight up. Where does the projectile land? Explain your answer.
6. A car is decelerating in a straight line. It launches a projectile straight up. Where does the projectile land? Explain your answer
7. A car is moving in a circular path with a constant speed. It launches a projectile straight up. Where do you think the projectile will land? Explain your answer.

Notes and Extensions:

1. Write a program in which the car accelerates while it is launching the projectile. Predict the landing and then investigate it.

2. What happens if the car changes direction while it launches the projectile, for example moves in a circle? Try to investigate this.

3.5 Simple Harmonic Motion

Age Group: 16+

Essential Questions: What are the characteristics of the motion of a vertical oscillating spring?

Recommended Time: 40-50 minutes.

Materials: NXT kit, retort Stand with clamps, ultrasonic NXT sensor, helical (coil) spring.

Activity Overview: In this experiment the students use an NXT and the ultrasonic sensor to investigate the change in vertical motion of an oscillating spring. Calculations of the amplitude and period can be made using the data from the resulting graph. [26]

Learning Objectives:

Study periodic motion and the characteristics of the displacement graphs.

Pre - Activity Discussion:

1. Introduce the concept of Periodic Motion and define amplitude (A), period (T) and frequency ($f=1/T$).

2. Discuss characteristics of periodic motion as in figure 3.5.1.

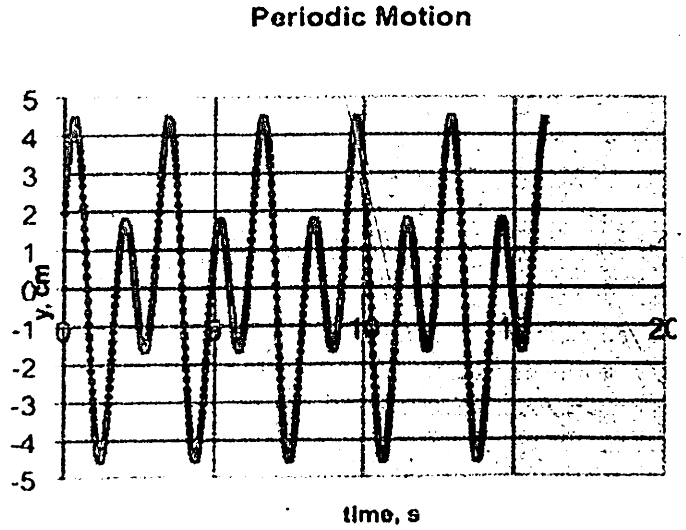


Figure 3.5.1 Periodic Motion

3. Discuss the characteristics of Simple Harmonic Motion as in example 3.5.2. Also explain restoring force is directly proportional to the extension and in the opposite direction (negative).

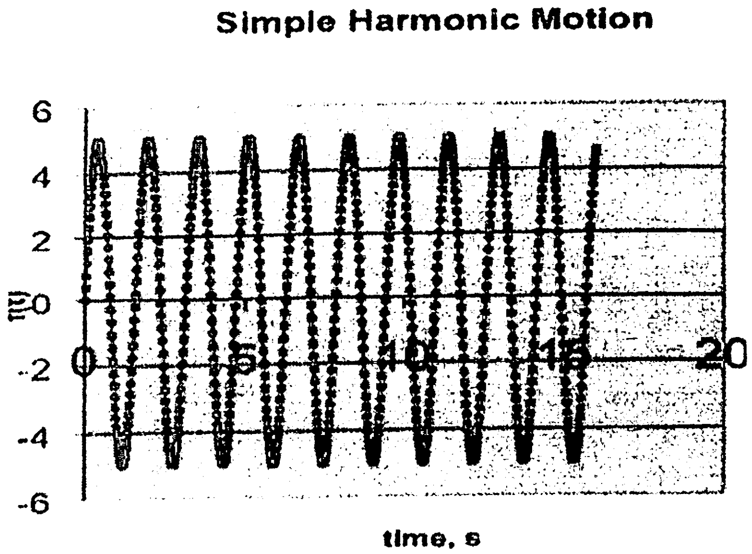


Figure 3.5.2 Simple Harmonic motion

4.Show the students the equation that describes Simple Harmonic Motion: $y= Asin(2nf)t$, where A = Amplitude, f = frequency of motion, t = elapsed time (s).

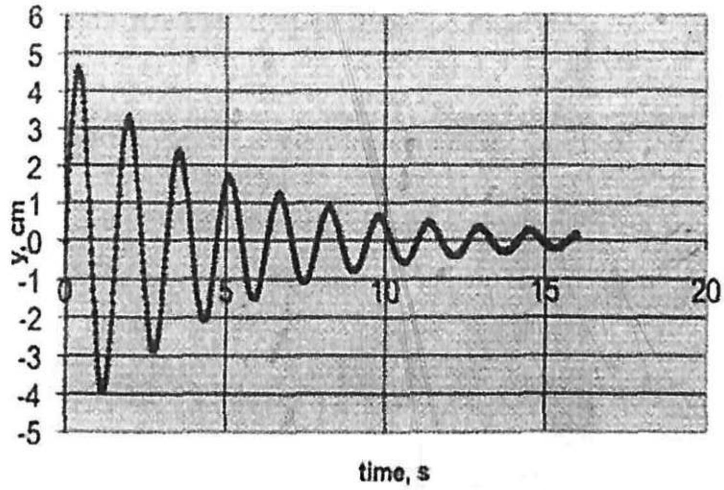


Figure 3.5.3 Damped periodic motion

5.Discuss the characteristics of damped motion and what parts of it are periodic.

Building Ideas:

1. Build a model of the spring-mass system using NXT, ultrasonic sensor, spring, and stand. See Figures 3.5.4 and 3.5.5

2. Ensure the ultrasonic sensor will read a hard flat surface e.g. wooden floor.

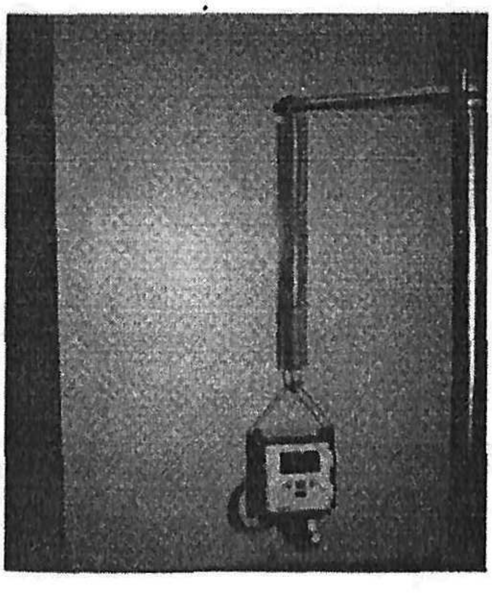


Figure 3.5.4: NXT set-up

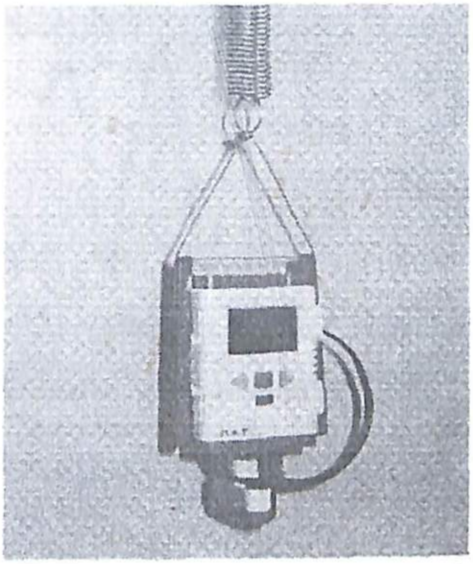


Figure 3.5.5: NXT ultrasound sensor set-up

Activity Instructions:

1. Using Mindstorms 2.0 or ROBOLAB Investigator, write a program to collect the NXT ultrasonic sensor data reading every 0.1s for 10s. See Figure 3.5.6

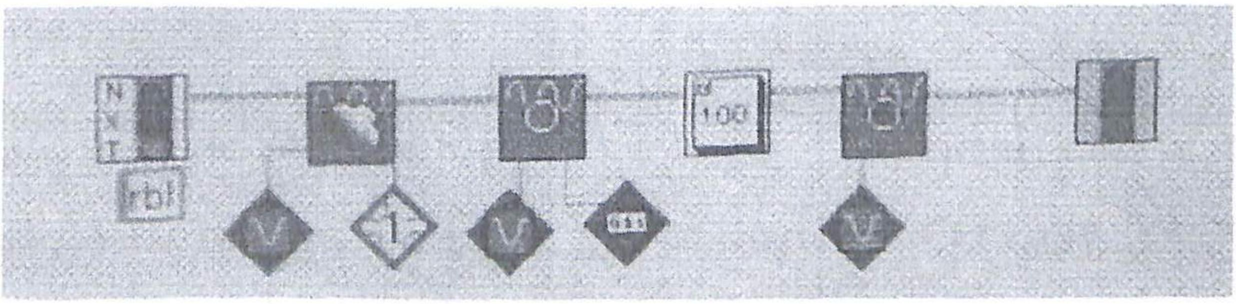


Figure 3.5.6 Robolab program

2. Start the program before you begin the oscillation.

3. Gently set the NXT on the spring to oscillate a few centimeters.

4. After finishing the experiment, upload the collected data.

5. Use the experimental data to find the amplitude and period. Calculate its frequency.

6. Repeat the experiment for different amplitudes.

Student Observations and Analysis:

Experiment	Amplitude	Period	Frequency
1.			
2.			
3.			

1. Describe the shape of the graphs.
2. How were they different?
3. For each graph, what changed over time?

Reflection Questions:

1. What factors affected the smoothness of the graph?

2. If the graph showed dampening, what may have caused it?

3. Did increased amplitude have an effect on the dampening.

3.6 Swinging with Gravity

Activity Level: 14+years

Essential Questions: Can astronauts measure time using a pendulum while they are traveling to Mars?

Recommended Time: 40-50 minutes.

Materials: NXT kit, NXT light sensor, retort Stand and Clamps String

Activity Overview: In this experiment a light sensor can be attached to the NXT to collect real-time data on the received signal change as the pendulum swings over a light/dark area. The period of the pendulum can be calculated from the resulting graph.

Learning Objectives:

Examine simple periodic motion.

Use the pendulum formula to compare measured and calculated period.

Activity Instructions:

1. Build the pendulum using some string, the NXT and a light sensor (see Figure 3.6.1).

2. Use a piece of white paper with a dark bar on it (or a white bar on a dark paper) and place it directly under the pendulum.

Figure 3.6.1 NXT and light sensor

3. Program the NXT using Mindstorms 2.0 or ROBOLAB to collect light sensor data during for 10 seconds.

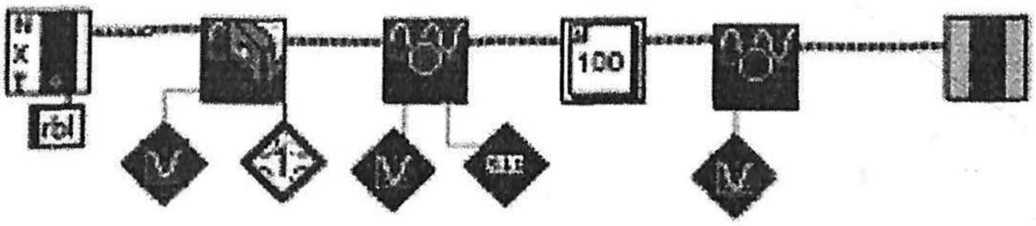


Figure 3.6.2 Sample ROBOLAB program

4. Set the pendulum in motion.

5. Upload the collected data using Mindstorms 2.0 or ROBOLAB.

6. Measure the length of the pendulum (length of the string + half of the NXT length) and record it in Table 1.

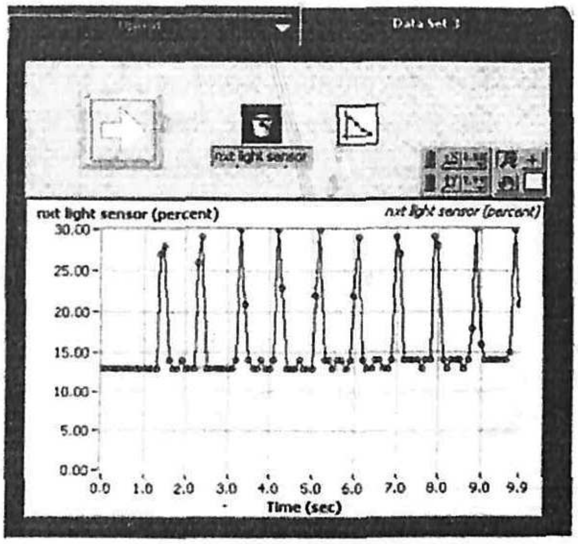


Figure 3.6.4: Sample NXT light sensor data

7. Calculate the period of the pendulum (T) from the light sensor data graph. Question: If the period of the pendulum is the time for one complete swing (out and back), what number of peaks will you have to include, to find the time difference?

8. Calculate the expected period (T) using:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

T is the period of oscillation (seconds) L is the length of the pendulum (meters) g is the Earth's gravitational acceleration (meters/seconds).

9. Compare the results for T from Steps 7 and 8.

10. Repeat the experiment but change the length of the pendulum.

Student Observation and Analysis

Table 1

L (Pendulum length)	T calculated	T experimental	% Error
1.			
2.			

Reflection Questions:

1. What can you say about the motion of the pendulum? Is it periodic?

2. How does changing pendulum length change the period of oscillation?

3. The gravitational acceleration in the mountains is less then at the sea level. What can you say about the period of the pendulum at high altitudes?

Notes and Extensions:

1.The data can also be used to determine the gravitational acceleration, if the length and the period of the pendulum are measured. [27]

2. Estimate the mass of the Earth using the experimentally obtained value of acceleration due to gravity. Use:

$$g = \frac{Gm_E}{r^2}$$

3.7 Terminal Velocity

Age group: 14+ years

Essential Question: Why does a skydiver reach constant velocity, while the force of gravity continues?

Recommended Time: 40-50 minutes.

Materials: NXT or RCX kits (parts for a single motor car), Mindstorms or Robolab software, LEDs (Light Emitting Diodes used as a load resistor), rotation sensor/ encoder, ramp with adjustable height. [28]

Activity Overview: The acceleration of any object is directly proportional to the applied Net Force. In free fall in the air, the object's acceleration is close to the acceleration due to gravity ($g = 9.8\ m/s^2$) if the air resistance can be neglected. However, as you know, when the object's speed is increasing, the force of air resistance increases as well, so the net force is decreasing. This is why a skydiver's velocity increases initially and then reaches a constant value, called terminal velocity. The velocity is not changing anymore, so the acceleration is zero, and the net force is zero too. [29]

In this experiment the situation will be modeled using a LEGO car running an electrical LEGO generator (LEGO motor) with a load resistance connected to its contacts. The force of resistance of the motor increases with increased speed. This results in the car achieving terminal velocity.

To create a constant acceleration similar to freefall, an incline or ramp will be used. To vary the acceleration and compare terminal velocities, the angle of the ramp can be changed.

Learning Objectives:

Students will learn from this experiment that for an object to reach terminal velocity, the resistant force changes and increases with the speed of the moving object.

Building Ideas:

1. Build a simple one-motor LEGO or NXT car.

2. Connect LEDs to the contacts of the motor. (See Figure 4.7.1)

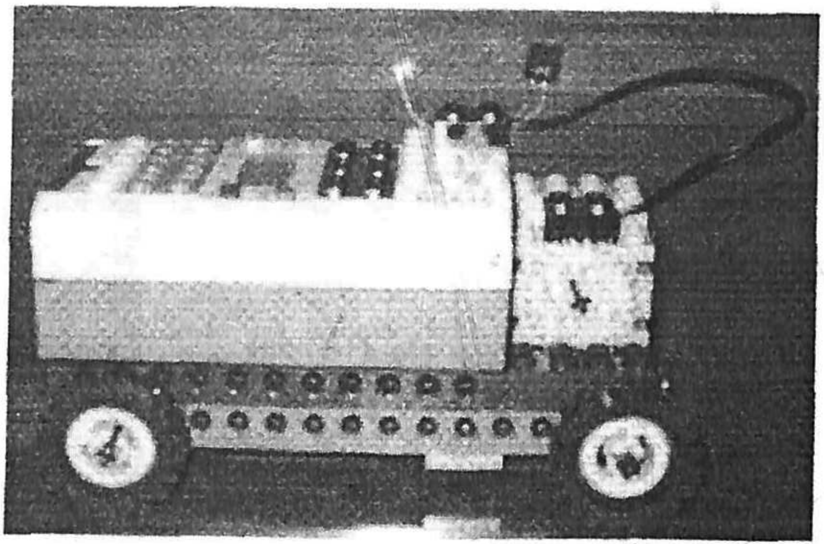


Figure 3.7.1 RCX Model car and LEDs attached to motor.

Activity Instructions:

1. Program your car to collect rotation sensor data.

2. To set up an inclined plane: take any 2-3 cm. long board and install it at an angle of 10-30 degrees.

3. Before you start the experiment on the incline, determine which direction of motion of the car will cause the LED to emit light due to its polarization.

4. Run the car down the ramp both ways so that you can see the change in speed of the car with the motor running and "LEDS on" versus the motor off and "LEDS off'. See Figures 4.7.2 and 4.7.3.

5. Compare both graphs.

6. Determine the terminal velocity from the "LEDS On" graph.

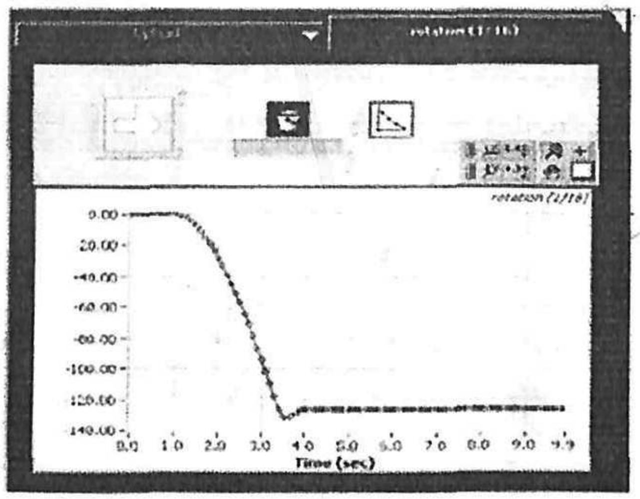


Figure 3.7.2 “LED’S OFF”

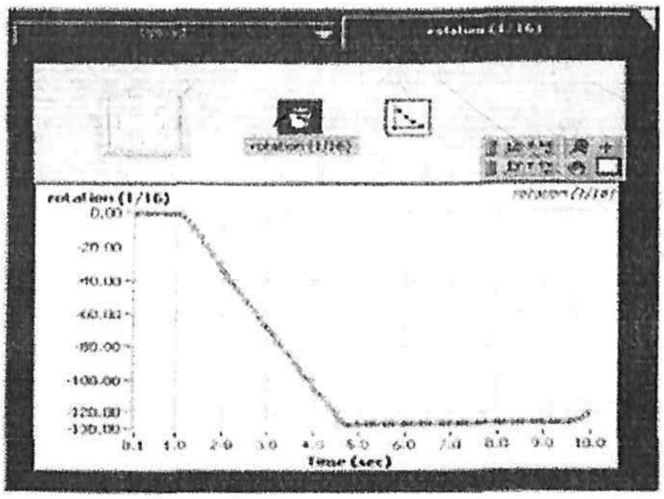


Figure 3.7.3 “LED’S ON”

7. Decrease the angle of the incline and with "LEDS ON", record the data to determine the new Terminal velocity.

8. Increase the angle of the incline and with "LEDS ON", record the data to determine the new Terminal velocity.

Student Observations and Analysis:

Experiment description	Observations	Data Collection
Experiment 1: Car is going down the incline and LED is not connected to the motor	What can you say about the speed of the car?	From the graph of motion what you can conclude about the speed of the car?
Experiment 2: Connect LED and turn on.	What can you say about the speed of the car?	From the graph of motion what you can conclude about the speed of the car?
Experiment 3: Decrease the angle of the incline and repeat Experiment 2	What can you say about the speed of the car?	From the graph of motion what you can conclude about the speed of the car?
Experiment 4: Increase the angle of the incline and repeat Experiment 2	What can you say about the speed of the car?	From the graph of motion what you can conclude about the speed of the car?

Reflection Question:

1. What is the relationship between the resistance force and the speed of the car?
2. Does changing the acceleration affect the size of the terminal velocity?
3. Conclude why all accelerating bodies on earth eventually reach terminal velocity?

4. Force and Motion

4.1 Gear Ratios and Speed

Age group: 14+

Essential Question: Why do you need to change gears?

Recommended Time: 40 - 50 minutes.

Materials: LEGO Gears two RCX rotation sensors

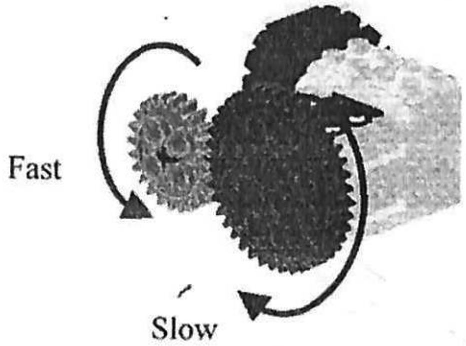


Figure 4.1.1 LEGO Gears

Activity Overview: The challenge of this activity is to investigate gear trains and relate them to speed. Data logging an angle sensor attached to the axles can determine total angle a wheel moves in a certain time. With two angle sensors, you can measure the motor axle angle versus the wheel axle angle. [30] Because for all machines:

Speed ratio = Distance moved by effort/Distance moved by load

In terms of a gear train:

Speed ratio = Angular distance turned by motor gear/Angular distance turned by wheel gear

Learning objectives:

1. Analysis of situations with a number of forces.
2. Model and analyze energy transformation.
3. Design and perform controlled investigations.
4. Refine investigations after evaluating variations and inconsistencies.

5. Analysis of applications of simple machines.

6. Use mathematical ratios to verify physical laws.

Building Ideas:

1. Set up a gear train to test various gear ratios (see Figures 4.1.2 and 4.1.3).

2. Put the rotation sensors/encoders at various positions along the train.

3. The rotation sensor on the motor axle will measure motor speed.

4. The rotation sensor on the end gear will measure wheel speed (no need to attach a wheel).

5. For RCX: setup the motor opposite one rotation sensor to drive the system.

6. For NXT: use one of the motor/encoders to drive the system.

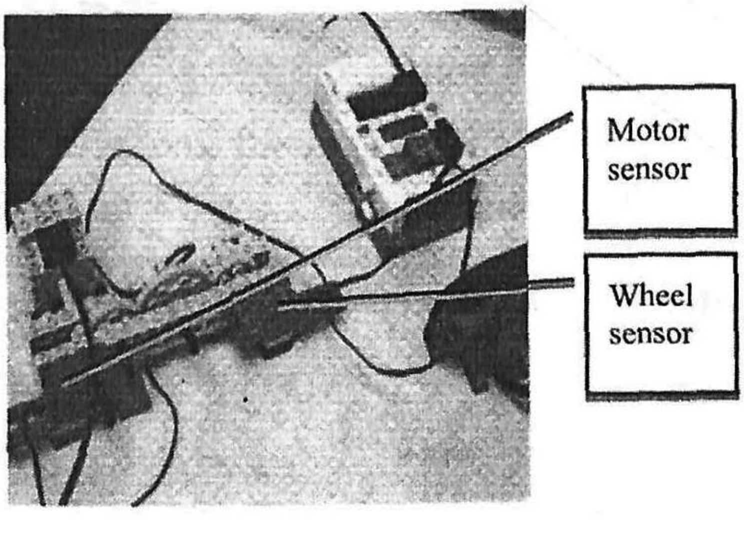


Figure 4.1.2 RCX set-up

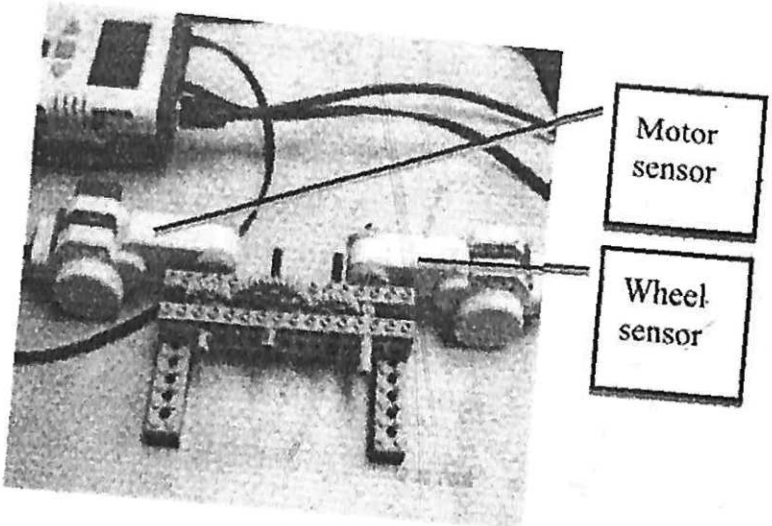


Figure 4.1.3 NXT set-up

Activity Instructions:

Once your gear train is built and set up with sensors and motor to go, attach these to the correct ports on the RCX (1 & 3 rotation, A for Motor) or NXT (A and C for motor encoders). Record the number of teeth for each gear along the train.

Programming Ideas ROBOLAB Investigator:

1. Use program level 4 or 5.
2. Zero and data log the two encoders/ rotation sensors.
3. Program the motor to run for a given time.
4. Download and run.
5. Upload data sets.
6. Using Compute tools determine the ratios of motor angle/ wheel angle.

ROBOLAB Front Panel Instructions:

1. Go to the Front panel to run the program.
2. You must input a time and download when ready.

. For RCX: Check the IR tower is seeing the RCX continuously.

For NXT: the USB link remains attached.

5. Once the gear train has run, there will be non-zero outputs from each sensor and the wheel/ motor ratio.

6. If there is a zero, reading it may be:

a. Your connections are incorrect (wrong ports or loose wires)

b. The sensor is running in reverse (negative values and this program gives the maximum 0) - reverse the sensor.

8. Run a number of times on the same two gears. Try changing the time length.

9. Record the average speed ratio from the computer for that particular wheel gear. Now move the wheel sensor to a different gear along the train and repeat the experiment.

11. Continue until all gears are tested.

Student Observations and Analysis:

Gear #	No of teeth	Speed = motor angle wheel angle
1 (Drive gear)		1
2		
3		
4		

Reflection questions:

1. Which turns faster small gears or big ones?

2. Is the speed ratio of drive (motor) gear to wheel gear consistent?

3. Does length of time affect it?

4. Is the speed ratio related to teeth ratio?

5. Do the in between gears affect this ratio?

6. For any given gear train, how is the speed ratio determined? How is this related to teeth?

7. What did you learn from this investigation?

Notes and Extensions:

1. Does the type or number of gears between the motor and wheel gears have any effect on speed? To verify this mathematically check the following (see Table 4.1.1):

	Drive gear	Gear 2	Gear 3	Wheel gear
No of teeth	8	24	40	24
Multiplying ratios		8/24 = 1/3	1/3 x 24/40 = 1/5	1/5 x 40/24 = 8/24

Table 4.1.1: Mathematical analysis of gear ratios.

Now try your combination and complete Table 4.1.2

	Drive gear	Gear 2	Gear 3	Wheel gear
No of teeth				
Multiplying ratios				

Table 4.1.2

2. These investigations are valuable for teachers wanting students to understand the simple machines and speed as well discovering some interesting facts about gear ratios.

3. Note that something can't be gained without something else being reduced and in this case its speed versus force.

4. This would also be great for lessons in math needing some practical applications of ratios.

4.2 Gear Ratios and Force

Age group: 14+

Essential Question: How do gear combinations reduce force?

Recommended Time: 60-90 minutes.

Materials: LEGO materials, 2 pulleys and string, 50g weights, force sensor or spring balance.

Activity Overview: This activity involves a simple construction of gear trains with weights or balances applied at each end to determine the mechanical advantage (MA) and relate it to the gear ratio. [30]

Learning Objectives

1. Analyze situations with a number of forces.
2. Model and analyze energy transformation.
3. Design and perform controlled investigations.
4. Refine investigations after evaluating variations and inconsistencies.
5. Analyze applications of simple machines.
6. Use mathematical ratios to verify physics laws.

Building Ideas:

1. Set up a gear train to test various gear ratios (see Figure 4.2.1).
2. Put pulleys with thread on each end.
3. Teacher can hang a force sensor or spring balance at one end and various weights at the end of the train or use weights on both sides!

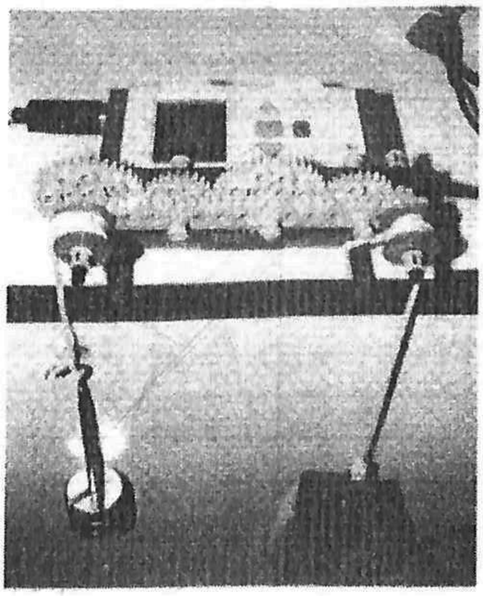


Figure 4.2.1: Experiment set-up.

Activity instructions

1. When your gear train is built and set up with pulleys, cord and hooks, attach 100 g weight on load gear (large) and a force sensor or balance on effort gear (small). (See Figure 4.2.2).

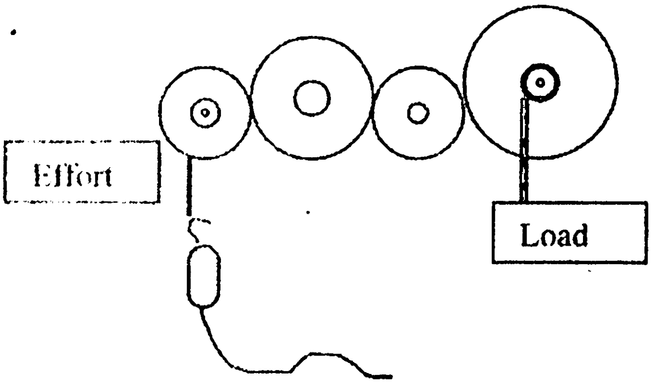


Figure 4.2.2 Gear train.

2. Record the force required to move the weight upwards.

3. Add another 100 g and record force.

4. Add another 100 g to record three results.

5. Now try the next gear along the train for the effort and repeat the above 3 trials.

6. Try swapping the load and effort gears.

Student Observations and Analysis

Gear ratio (# teeth load/# teeth effort)	Weight added	Force required	MA (load/effort)

Table 4.2.1: Experimental data

8. Is the Mechanical Advantage ratio consistent for each gear ratio?

9. Does the increase in weight added affect the efficiency?

10. Is *MA* related to Gear ratio?

11. Combining the Speed ratio and Mechanical advantage you can determine the efficiency of this gear train:

Efficiency = MA/SR x 100 %

Speed ratio (SR) = Distance moved by effort/ distance moved by load = # teeth load gear/ # teeth effort gear.

Determine the efficiency of your gear train!

Reflection Questions

1. To reduce effort required and so use a ratio of gears with the greatest mechanical advantage what is the best combination?

2. How efficient is the system?

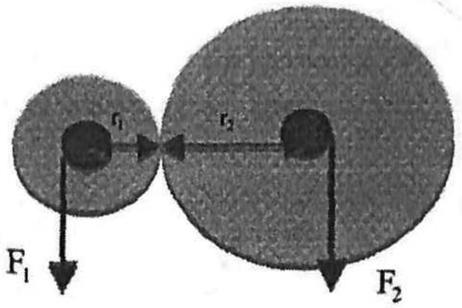
3. What can you do to increase efficiency?

Notes and Extension

1. In the Activity : Gear Ratios and speed, the speed ratio increased with gearing up the number of teeth on the motor cog. There is a compromise however, as students will often discover in attempting to increase the speed of their super dragster. Gaining speed loses rotational force or torque.

Using Moments about the center of a gear and transferring force to a meshed gear, it can be shown:

$$\frac{F_1}{F_2} = \frac{r_1}{r_2}$$



4.2.3 Gears Ratio and Applied Force

This means the smaller the gear on the wheel and greater speed ratio, the weaker the force!

2.Mechanical Advantage is also an important concept for machines to show the effort force can be reduced.

MA = Load /Effort or for gears

MA = Output force from Wheel/ Input force from Motor

MA > 1 for a geared down system

3.I have tested speed ratio and noted that it is only dependent on teeth number. However, the force ratio is affected by internal forces of friction and tension in the string; hence, efficiency should also be determined.

Efficiency = MA/speed ratio x 100 %

4.3 Newton's Laws Demonstrations

Age Group: 14+

Essential Questions: What can a robot teach you about Newton's three laws of motion?

Recommended Time: 2-3 lessons.

Materials: NXT or RCX kit, measurement tools for the students to support their demonstrations with data.

Activity Overview: In this activity, students will create a robot system that interacts with the real world. In physics, an interaction occurs when objects exert a force on one another. Examples of interactions could be pulling a wagon, pushing on a wall, or sliding across the floor. It is not hard to create an interaction because any time an object's motion changes, it is the result of an interaction. In this activity, it is up to the student to come up with creative interactions that helps them demonstrate the meaning of Newton's three laws. One important aspect of this activity is that students support their demonstrations with data.

Learning Objectives:

By the end of this activity, students will be able to:

1. Demonstrate interactions between a robot system and objects in its environment.

2. Demonstrate the application of Newton's three laws to a robot interaction.

3. Use data to support the demonstration of Newton's three laws.

Pre-Activity Discussion Questions:

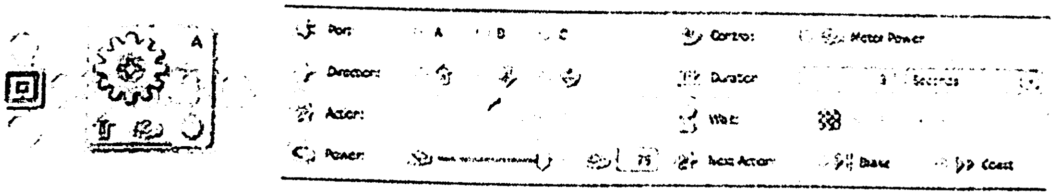
1- In physics, what are interactions?
2- What are examples of interactions in everyday life?
3- Pick a few interactions and describe how all three of Newton's three laws apply to these interactions?

Building Ideas:

The details of the systems the students will build depend upon their ideas for demonstrating the laws. If the students have limited building experience with the LEGO systems, I recommend they start with either the single motor or double motor systems.

Programming Ideas:

While the details for the programming of the robot systems built by your students will depend upon their specific ideas, it is likely that the programming will consist primarily of turning on a motor at a certain power level for a certain amount of time. One useful programming technique for this activity is to have the robots "coast" to a stop rather than stop abruptly. Figures 4.3.1 and 4.3.2 show code in the Mindstorms and Robolab software environments.



Port: A B C
Direction:
Action:
Power: 75
Control: Motor Power
Duration: 3 Seconds
Wait:
Next Action: Brake Coast

Figure 4.3.1 Mindstorms code to turn on motor A at 75 % power for three seconds and then let it coast to a stop.

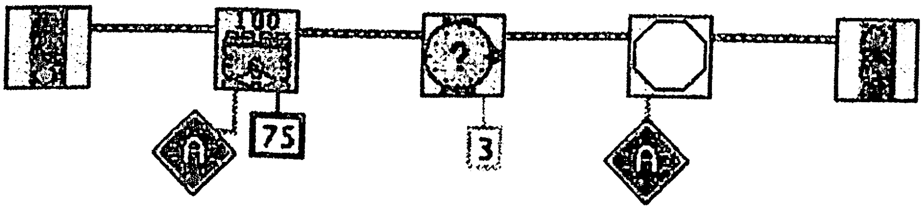


Figure 4.3.2 Robolab code to turn turn on motor A at 75 % power for three seconds and then let it coast to a stop.

Activity Instructions:

1. This activity can be done in three different ways. You can:

a. Apply all three laws to a single interaction - a robot skidding to a stop, for example. How can you use this single interaction to demonstrate all three of Newton's laws?

b. Apply each law to a different interaction - the robot starting to move for Newton's second law, the robot moving at a constant velocity for Newton's 1st law, and the robot stopping for Newton's third law.

c. Conduct this activity with a combination of a. and b. above.

2. Review Newton's three laws and sketch your ideas for building a LEGO system that demonstrates all three laws. If you have done other projects in this work, think about how the laws apply to those projects. If this is your first project, think about how a LEGO device can exert forces on other objects (LEGO or non-LEGO) and how those objects exert forces on the LEGO system.

3. Brainstorm ideas for how you will collect data to support your demonstrations. What will you measure and how? If you do not have the ability to collect data to support your ideas, return to step one and brainstorm a new interaction. NOTE: Do not underestimate the time required by steps 2 and 3. Plan your efforts well to ensure high quality interactions supported by high quality data.

4. I recommend that you take the time to share your ideas with the class. It is likely that most groups of students will be conducting different demonstrations. However, sharing ideas related to data collection may be very useful. Data collection methods for supporting a demonstration of Newton's third law may be identical even if the actual interactions are very different.

5. Once you are ready, build your system that demonstrates Newton's laws. Collect data to support your demonstrations. Consult with your instructor to determine how you will present your work.

Student Observations and Analysis:

Students should record their data in accordance with the practices of the class. I do not recommend any specific system because the method you choose to record your measurements depend highly on the system you choose for the actual data collection. A student is likely to record data differently from a spring scale (force-meter) compared to a student who collects data from a force probe connected to a computer. Keep the final presentation of the student work in mind when deciding on the best way to record and represent data in this activity.

Reflection Questions:

1. How will you and you; classmates present your demonstrations and data?

2. Which law did you find the easiest to demonstrate? Describe what you did and how you used data to support the demonstration.

3. Which law did you find the hardest to demonstrate? Describe what you did, why it was hard. Describe how you used data to support the demonstration.

Notes and Extensions:

1. Students can present their demonstrations in many different ways. Some examples are:

a. A traditional lab report.

b. A classroom demonstration of the interactions and presentation of data that supports the application of each law.

c. An audiovisual presentation - a digital movie, or slideshow that stands alone to communicate how the student's projects demonstrated Newton's laws and how these demonstrations were supported by data.

2. An alternative approach to using traditional forms of data (i.e. numerical data) is to use qualitative observations as evidence for each law. For example, attaching a LEGO vehicle to a small wagon can demonstrate Newton's first law. Place a marble in the wagon. When the LEGO vehicle moves forward, the marble remains at rest. Relative to the wagon, it moves backwards. When the wagon stops, the marble stays in motion until it strikes the front of the wagon.

4.4 Newton's Second Law Investigation

Age group: 16+years

Essential Question: How can you change the velocity of a moving object?

Recommended Time: 40 - 50 minutes.

Materials: NXT or RCX Kit with rotation sensor, set of weights, pulley

Activity Overview: This activity will introduce students to the relationship between the acceleration, force, and mass. Students will experiment with the motion of an object when the force is applied to it.

Students will qualitatively find that the acceleration of an object increases proportionally to the net force acting on the object and inversely proportionally to the mass of the accelerating system.

$F = ma$

$a = F/m$

Learning Objective:

Develop an understanding of the relation between acceleration, force, and mass.

Building Ideas:

1. In this experiment you will use NXT/RCX car, which will be accelerated by the external force applied to it.

2. You need also a pulley, a string, and a hanger with a set of masses to vary the forces applied to the car.

3. You need rotational sensor for this experiment. For the NXT, the rotational sensor (encoder) is part of the motor. For the RCX, do not install a motor, but attach a rotational sensor to one of the axes instead.

4. Experimental setup is shown in Figure 4.4.1.

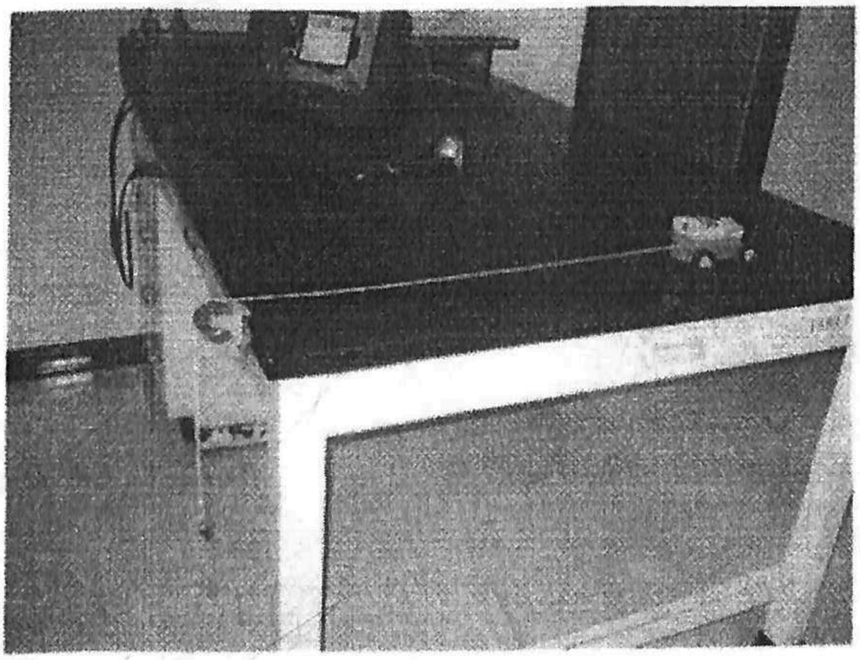


Figure 4.4.1: Experiment arrangement

Activity Instructions:

1. Program the NXT/RCX to collect the rotation sensor/encoder readings.

2. Measure the mass of the NXT/RCX car, M_1____________________

3. Measure the mass of the hanger with additional masses, M_2__________

4. In this experiment you will distribute additional masses between the hanger and the NXT/RCX car. As a result the total mass of moving system will be kept constant ($M = M_1 + M_2$), but the force applied to the system will be equal to the weight of the hanger with remaining masses on it.

5. Transfer some of the masses from the hanger to the NXT/RCX car and record the mass of the hanger with remaining masses on it (m) in Table 1.

6. Start collecting data from the NXT/RCX and release the system.

7. Upload the data from the encoder (NXT) or rotation sensor (RCX).

8. Repeat steps five and six for different distributions of masses between the NXT/RCX and the hanger.

9. See Figure 4.4.2 for the sample graph from the rotation sensor data. [24] [22]

Student Observations and Analysis:

Table 1

	Total hanging mass (m)	Total mass of the system ($M=M_1+M_2$)	$F_{net}=mg$ (neglecting friction)	$a_{calculated}$	$a_{experimental}$
Experiment 1					
Experiment 2					
Experiment 3					

Calculate the experimental value of linear acceleration form the angle sensor data. Figure 4.4.2 shows experimental data from the RCX rotation sensor. Note: For the RCX rotation sensor the data is represented in units of (1/16) of a revolution. For the NXT encoder, the data is represented in degrees.

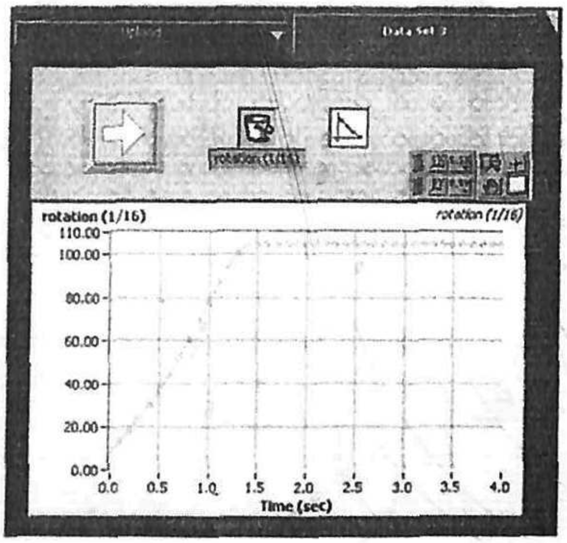


Figure 4.4.2: RCX rotation sensor data.

Convert the angular data into the linear displacement data using:

Linear distance = (number of revolutions) x 2πR where R is the radius of the wheel of the car.

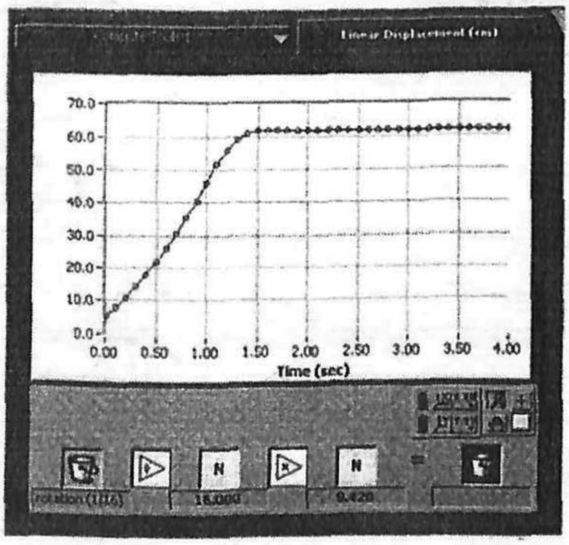


Figure 4.4.3: Graph of Linear Displacement (cm) (R wheel = 1.5cm)

Velocity can be found as the first derivative of the Linear Displacement (see Figure 4.4.4). Note that the velocity linearly increases with time. The acceleration can be found as the slope of the velocity graph (see Figure 4.4.5).

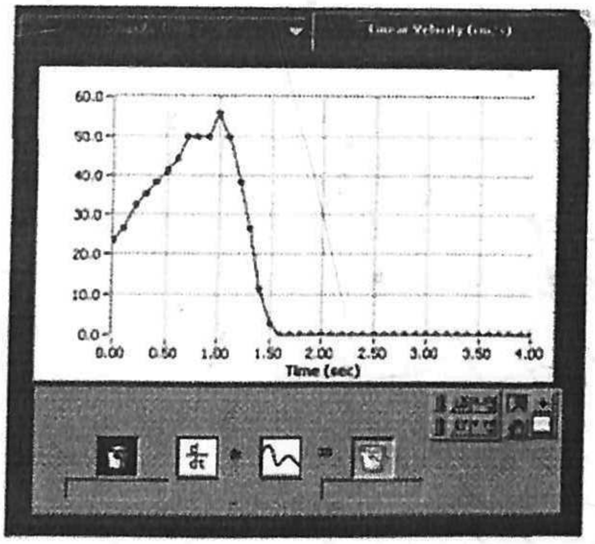


Figure 4.4.4: Graph of Linear Velocity (cm/s)

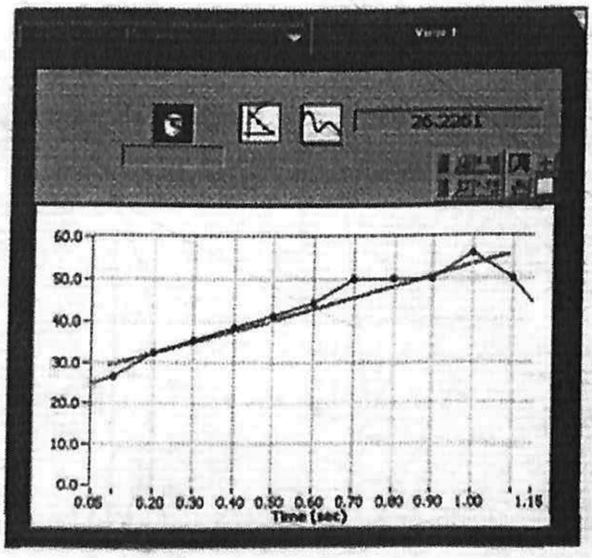


Figure 4.4.5: Value of slope (cm/s^2)

Record your experimental values for acceleration in Table 1. Using a spreadsheet, plot a graph of experimental acceleration as a function of F_{net}. The slope of the graph should be equal to 1/m, where m is a total mass of the system.

Reflection Questions:

1. How were you able to control the force applied to the system?

2. Did the vehicle in your experiment have a constant speed or not? Please explain your answer using the data from your experiment.

3. If the total mass of the system remains the same (by transferring weights from the car to the hanger), how does acceleration changes in relation to the hanging mass?

Notes and Extensions:

In order to decrease the effect of the friction, the hanging mass should not be too small. Otherwise, the pulling force would be comparable to the force of friction and the motion is more complicated for analysis.

4.5 Measuring Friction

Age Group: 16+

Essential Questions: Can a robot help me learn the meaning of friction?

Recommended Time: 45-90 minutes.

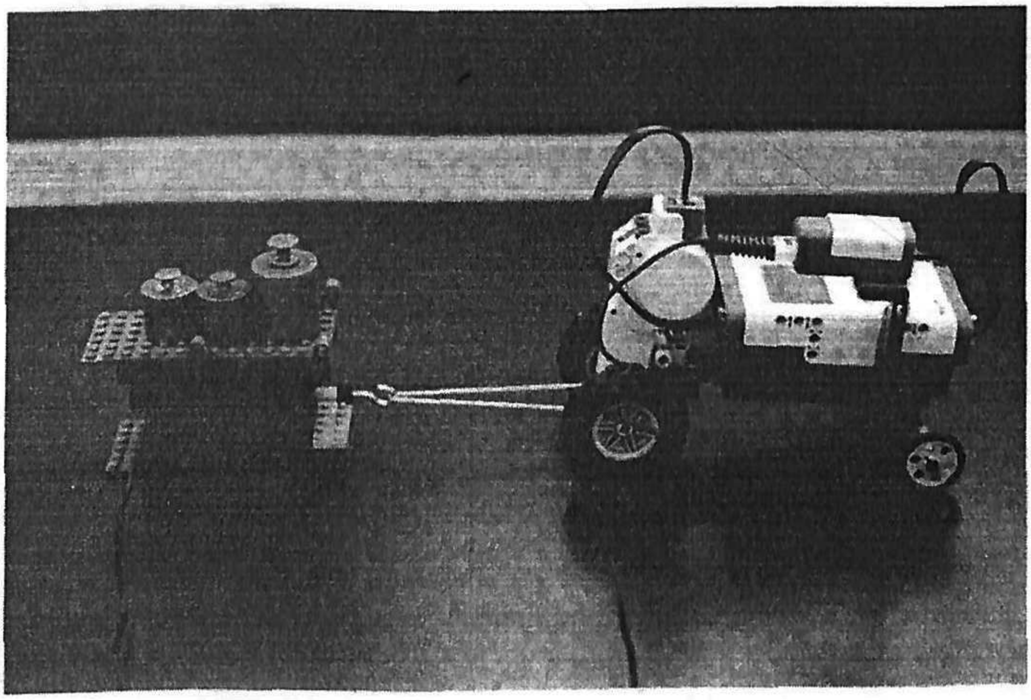


Figure 4.5.1: Experimental setup.

Materials: NXT or RCX kit, set of weights, force probe, mass or weight scale.

Activity Overview: In this activity, students will use Coulomb's law of friction ($F_f = \mu F_N$) to determine the coefficient of static and kinetic friction for several surfaces such as tabletops, different types of paper, and different floor surfaces, wood. The LEGO robot and a force sensor is an ideal tool for conducting this investigation because it allows for hands free, repeatable experiments.

This activity is suitable as an investigation of Coulomb's law of friction alone or as a supporting activity for an engineering challenge such as a hill climb. See the notes and extensions section of this activity for ideas.

Pre-Activity Discussion Questions:

1. What is friction and what would the world be like without friction?

2. Why is friction important?

3. What factors affect the amount of friction and what equation relates those factors together?

4. When studying the factors that affect friction, you refer to something called the "Normal" force. What is it and how do you measure or calculate its amount?

Learning Objectives:

By the end of this activity, students will be able to:

1. Differentiate and measure frictional forces and normal forces

2. Calculate coefficients of friction

3. Relate Coulomb's law to objects in everyday life

LEGO Sample Building Instructions:

The example of a single motor vehicle that can pull a force meter sled (Figure 4.5.3). To conduct this experiment, the robot only needs to drive straight for a specified amount of time. If you are conducting this investigation with an RCX, I recommend that you build a model with a gear ratio that reduces the speed of the unit while increasing its pulling force. This will help prevent your wheels from spinning and allow you to pull the sled at a constant speed.

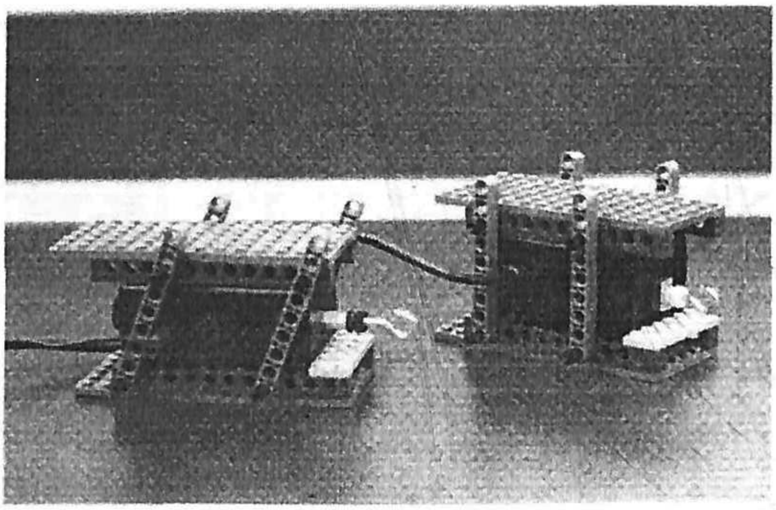


Figure 4.5.3 Vernier Force Sensors

Sample Programming and Data logging Instructions:

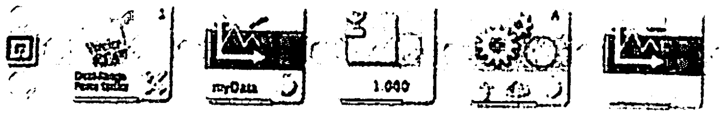
As with most activities in this work, this activity can be completed with different combinations of robot hardware, programming software, and data logging software. If you are using the Vernier Dual-Range Force Sensor, the table below represents your hardware and software options. If you are conducting this activity with another digital force sensor, consult the manufacturer for your options. In general, if your sensor does not communicate directly with the robot hardware then you need to do the programming and data logging separately.

Hardware	Programming	Data Logging
NXT	MINDSTORMS 1.0-2.0, ROBOLAB	MINDSTORMS 2.0, ROBOLAB Investigator Vernier Logger *Pro*
RCX	ROBOLAB	Vernier Logger *Pro*

Table 5.5.1: Hardware and Software Options for the Vernier Dual Range Force Sensor

Programming and Data Logging with Mindstorms 2.0

With the release of version 2.0 of the Mindstorms Education NXT Software, the user can program the robot to move and collect data. The following is a sample program used in a friction investigation Activity 1 (Figure 4.5.4).



Zero the Force sensor

Power 50
Duration 4 seconds

5 Second duration
100 Samples per second
Uncheck "Wait for Completion"
Vernier Force 10N in Port 1

Figure 4.5.4 Mindstorms 2.0 program to collect data while running a motor.

Activity Instructions:

1. Build a sled that can hold the force meter (see Figure 4.5.3).

2. Configure your robot and data collection software to collect force data while pulling the force sled. Pick your surfaces to test and tune the speed of your robot so that its wheels do not spin while pulling.

3. Determine the time to pull the sled based on your lab surface.

4. Once your robot is pulling without spinning its wheels and pulling at a constant speed, you are ready to collect data.

5. Run your robot while collecting data and observe the resulting graph.

6. Analyze your data to determine the maximum force of static friction and then the average force of kinetic friction. See the Programming and Data logging section of this activity for examples. Record the results of your analysis in the Student Observations and Analysis section of this activity.

7. Repeat steps five and six, 3 - 5 times and obtain an average for both the force of static friction and kinetic friction.

8. Measure the mass of your force sled and determine the normal force (F_N) acting on the sled. Record the results of your analysis in the Student Observations and Analysis section of this activity.

9. Use Coulomb's Law ($F_f = \mu F_N$) to determine the coefficients of static and kinetic friction.

10. Repeat these steps for all surfaces being tested.

11. See the Notes and extensions of this activity for application and design challenges connected to this friction analysis.

Student Observations and Analysis:

Data Table 1

Surface	Mass of the Sled	F_N	$F_{fstatic}$ **Trial 1**	$F_{fstatic}$ **Trial 2**	$F_{fstatic}$ **Trial 3**	μ_s

Data Table 2

Surface	Mass of the Sled	F_N	$F_{fkinetic}$ **Trial 1**	$F_{fkinetic}$ **Trial 2**	$F_{fkinetic}$ **Trial 3**	μ_k

Reflection Questions:

1. In everyday life, where is it important to use surfaces with high coefficients of friction?

2. In everyday life, where is it important to use surfaces with a low coefficient of friction?

3. Did any of the results of this investigation surprise you? If so, explain.

4. Does the coefficient of friction depend on the mass of the objects sliding over one another? Describe an experiment you could use to investigate this question.

5. At any point in your investigation did your wheels spin, preventing your vehicle from pulling the sled? What did you do to resolve the situation? Describe your solution with the terms used in this lab investigation: friction, normal force, and coefficient of friction.

5. Energy

5.1 Microphone Sound Reduction

Age Group: 14+

Essential Questions: If a tree falls in the forest, how do you quiet the sound?

Recommended Time: 90 minutes

Materials: NXT, NXT Sound sensor, NXT Motor, 9-volt buzzer.

Activity Overview: In this activity, students will explore sound waves. Specifically, they will use the NXT sound sensor to explore how sound waves work by designing experiments to investigate the variables that affect the measurement of a sound wave's loudness. For instance, how does the distance between the sources of a sound affect the measurement of the sound wave's loudness? How does the orientation (direction) of the sound source affect the measurement of loudness? How do obstacles between the source and sensor affect the measurement? Are there other variables that affect the measurement of a sound's loudness? It is likely that students will be able to generate hypotheses that describe relationships between variables; the point of the activity, therefore, is to provide them with practice at designing a controlled experiment that either supports or fails to support their hypotheses.

While designing their experiments, conducting observations, and drawing conclusions, students will explore what loudness is and how it is measured. Before they begin, however, students should review the relevant units of measurement for a sound wave's loudness. The NXT sound sensor does not report sound level readings in true decibels (dB). This does not, make the sensor less useful for the investigations in this activity. It does mean, however, that students should be aware of the units used by the NXT sound sensor if they wish to develop specific mathematical relationships between variables.

Pre Activity Discussion Questions:

One of the biggest challenges to students and teachers about the topic of sound is that in spite of its omnipresence, you cannot see it! An exceptional visual and interactive model of sound waves can be found online. I encourage you to visit the interactive simulation at the web address below as a companion to the discussion questions. http://phet.colorado.edu/simulations/sims.php?sim=Sound [30]

1. What is the difference between a sound wave's wavelength, frequency, and amplitude? Which of these best describes the loudness of a sound?

2. How does sound transfer energy? In other words, how does a sound do work? How do the terms energy, power, intensity, and relative intensity?

3. What direction do sound waves move from a source?

4. Assuming that there is no energy lost by a sound wave, why is it not as loud the further away you move from a source?

Learning Objectives:

By the end of this activity, students will be able to:

1. Describe sound waves in terms of a transfer of energy.

2. Measure the loudness of a sound wave and relate this measurement to a wave's amplitude, energy, power, and intensity.

3. Create an experiment that investigates which variables affect the measured loudness of a sound wave.

Building Ideas:

I outline here a few ideas to consider when designing sound experiments for this activity.

1. To help ensure that your sound measurements are measurements of waves traveling through the air, it is necessary to isolate the sound sensor from vibrations that come directly from the sound source motor and from the tabletop. Figure 6.1.1 shows two techniques for isolating the sound sensor. The first technique is to mount the sound sensor on a separate structure and the second technique is to place all equipment on top of packing foam.

2. If students are exploring the effect of an obstruction (i.e. sound absorption) between the source and sound, make sure they consider how sound waves diffract around the edge of the obstruction. This could lead to another investigation.

3. The motor shown in Figure 6.1.1 works well and is well suited for several investigations. The classroom to motor noise ratio, however, may make it impractical to use. Consider using a loud (□ 95 dB) Piezo Buzzer. This ensures a strong signal to

noise ratio for your data collection. It can be easily interfaced with the NXT using the NXT to RCX motor/sensor cable. See Figure 5.1.2 for details.

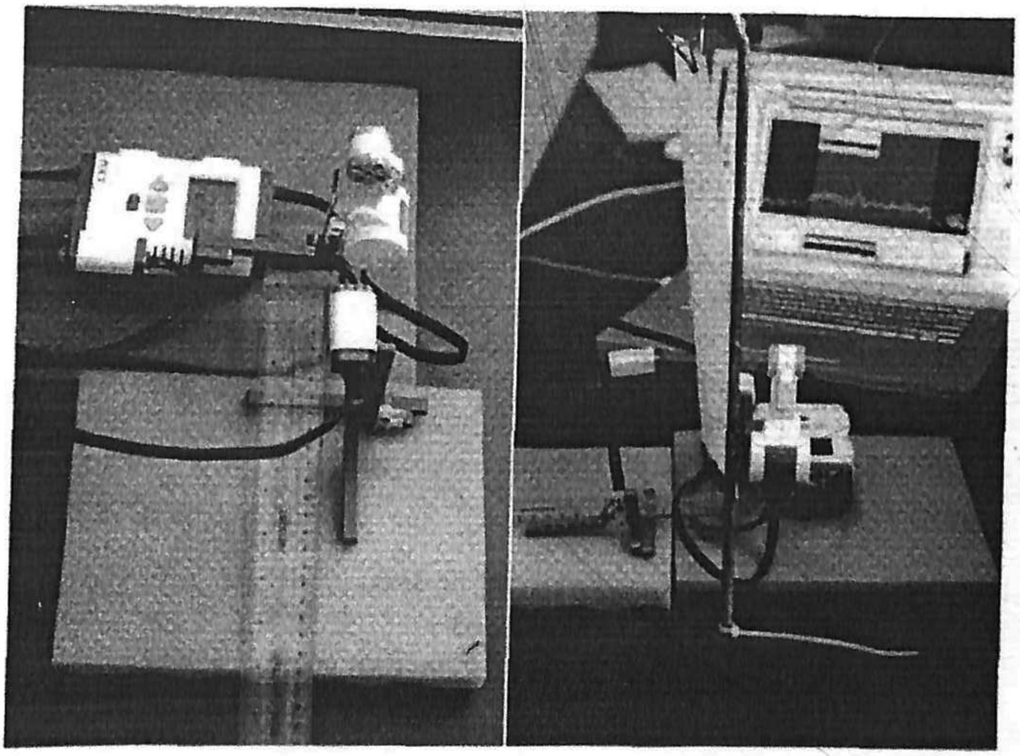


Figure 5.1.1. The design on the left allows for easily varying the distance and relative angle between source (an NXT motor) and sensor.

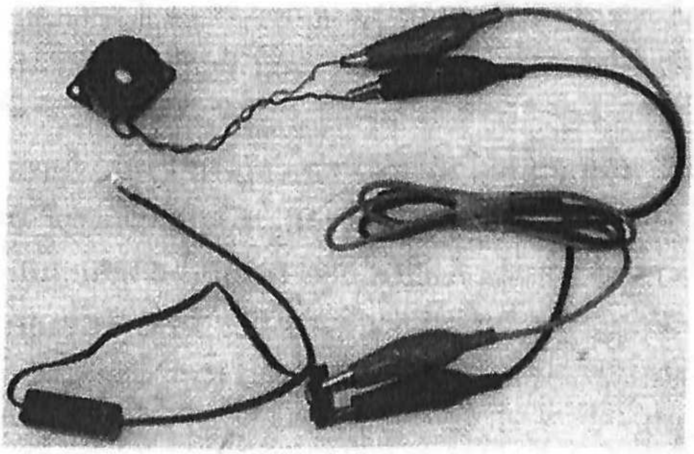


Figure 5.1.2 Wiring for Piezo Buzzer and Legacy Connector

4. Figure 5.1.3 shows an experimental design utilizing the 9V DC Piezo buzzer. You can see in the computer screen that the NXT sound sensor's threshold is reached (left) but when paper "ear" protection is put on the sound levels are reduced considerably. The

loudness of the Piezo buzzer allows for flexibility in the design of many experiments. In other words, you do not have to be as concerned about low-level background noise in the classroom.

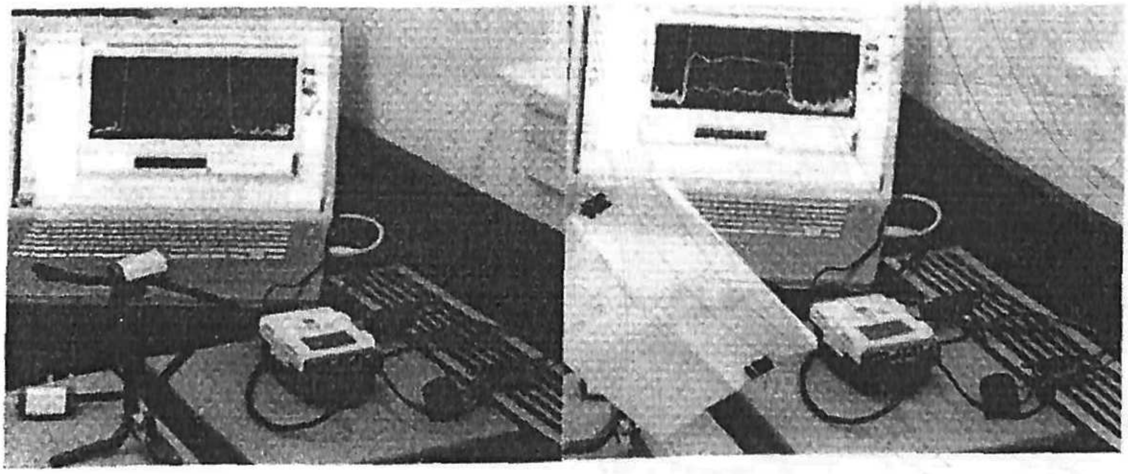
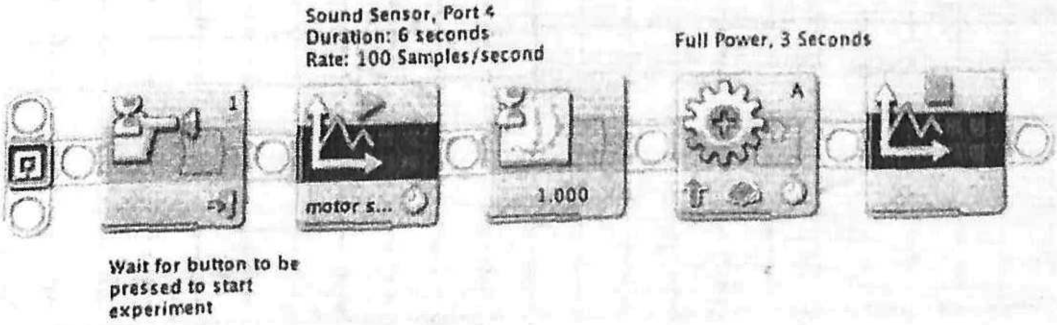


Figure 5.1.3: The Piezo buzzer is used as the sound source here.

Data Logging Ideas:

Two challenges when collecting sound data with the NXT sound sensor include understanding the units used in measurements and dealing with background noise. To help manage both of these issues, we recommend that students determine baseline conditions and collect baseline data. Figure 5.1.4 shows example Mindstorms 2.0 code for a sound experiment.



Sound Sensor, Port 4
Duration: 6 seconds
Rate: 100 Samples/second

Full Power, 3 Seconds

Wait for button to be pressed to start experiment

Figure 5.1.4. Mindstorms 2.0 code for collecting sound data from a running motor.

Activity Instructions:

1. The goal of this activity is to study the variables that affect the measured loudness of a sound wave. Your first step in such an investigation is to determine which variables you will test. Explore this question with either a simulation (see Pre-Activity Discussion

Questions section above) and/or informal experimentation using a set-up similar to Figures 5.1.1 and 5.1.3. What will affect the measured loudness of a sound wave? Refer to the Student Observation and Analysis section of this activity to guide you as you record your results.

2. Pick at least one of the variables that you identified in your experimentation. Design a controlled experiment to document the relationship between this variable and the measured loudness of your source. Be careful with your experiment and do your best to control for other sources of sound in your classroom. Use the dB setting for your sensor.

3. Record the results of your investigation. Refer to the Student Observation and Analysis section of this activity to guide you as you record your results.

4. Share your results with your classmates and document the effect that different variables have on the measured loudness of a sound wave.

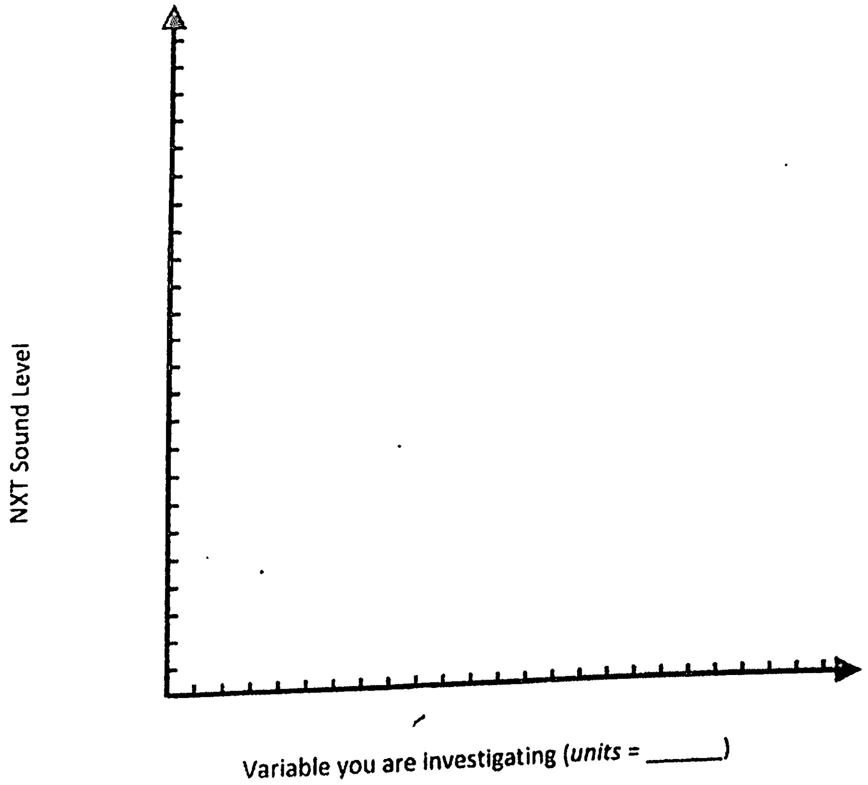
5. If time allows create sub groups that tested the similar variables. Determine if the results of these investigations are repeatable.

6. Use the reflection questions of this activity to guide you as you determine what conclusions you can draw from these investigations.

Student Observations and Analysis:

1. Problem definition - Exploring variables that Affect Measured Loudness

Variable	Describe what you did to explore this variable. How did it seem to affect the measured loudness of the sound



Now draw a graph of NXT Sound Level versus your chosen variable.

Reflection Questions:

1. What is meant by a sound's "loudness"?

2. How does a sound's "loudness" relate to the amplitude, energy, power, and intensity of the wave?

3. Throughout the activity, I used the phrase "measured loudness". Is there a difference between the loudness of a sound and its measured loudness?

4. What variable did you test in this activity and how does that variable affect the measured loudness of a sound?

5. Did anyone else in your class test the same variable? Were their results consistent with yours?

6. What explains your results? In other words, what explains the relationship that you discovered between your variable and the measured loudness of the sound?

Notes and Extensions:

1. Sound experiments are always a challenge to do in a full classroom of students. Three techniques that work to help manage this challenge are a) coordinate data collection so that the room is quiet during data collection, b) use a separate room for the sound experiment, or use a loud source like the Piezo buzzers mentioned in this activity.

2. One variable the students may not think to test is the sensor itself. Given identical conditions, do all NXT sound sensors report the same readings?

3. If you have the time, it is a worthwhile exercise for students to try and reproduce each other's results.

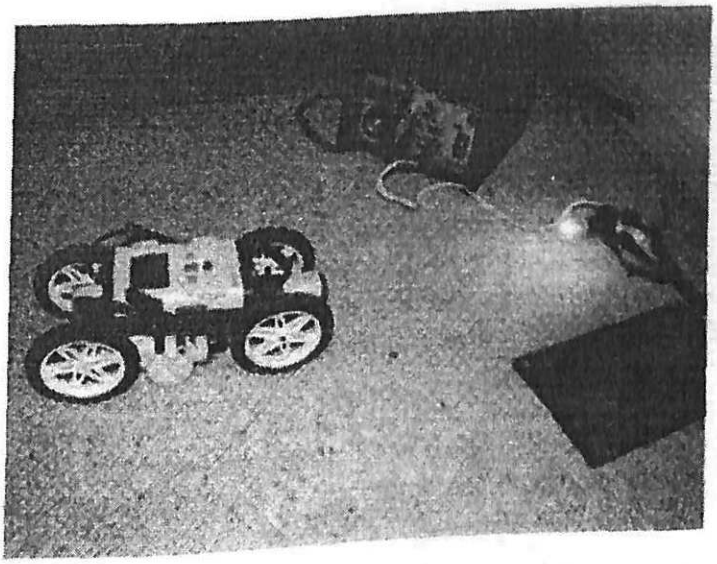
5.2 Wave Intensity versus Distance

Age Group: 14+ years

Essential Question: How does the intensity of waves such as light brightness vary with distance from the source?

Recommended Time: 40- 50 minutes.

Materials: Lego Car (RCX/NXT) with a rear light sensor pointing back and a rotation sensor attached. Point source of light (a small, bright bulb able to transmit in all directions is best).



5.2.1 LEGO car.

Activity Overview:

This activity investigates the inverse square law for wave propagation. Using the uniform motion of a LEGO car away from the source, a graph of intensity versus distance can be displayed and analyzed. Using the sensors for the NXT, both light and sound can be investigated.

As an introduction, a discussion should be had of the propagation of waves from a point in all directions and the resulting decrease in energy as the wave moves outwards. Models of ripples in water can be used.

Learning objectives:

1. Students use wave models to explain the transfer and transformation of energy.
2. Design and perform controlled investigations.
3. Refine investigations after evaluating variations and inconsistencies.
4. Illustrate and analyze the inverse square mathematical relationship.

Building Ideas:

A LEGO car with fixed axles will ensure linear motion. One motor is sufficient. The objective is to get the car moving at constant speed so that distance and time for light readings are varying equally.

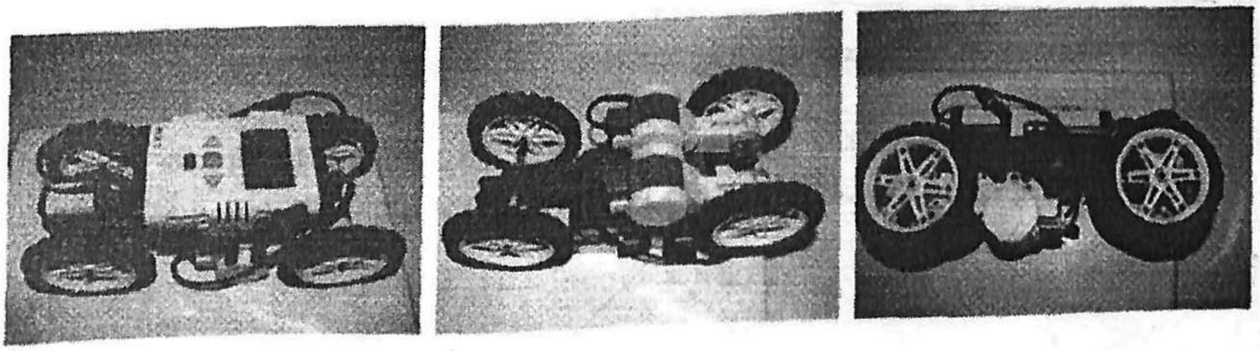


Figure 5.2.2 Fixed Axle car.

Programming Ideas:

The program involves data logging both light intensity and number of rotations (distance) as the car moves slowly away from the light.

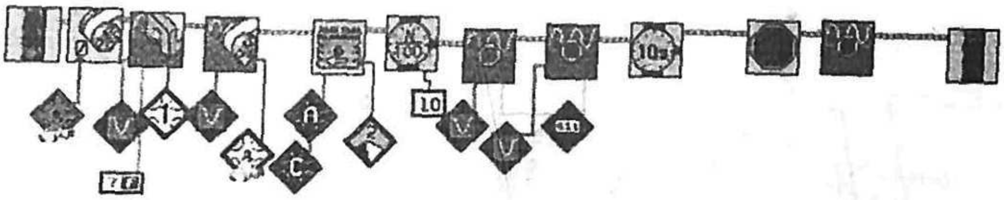
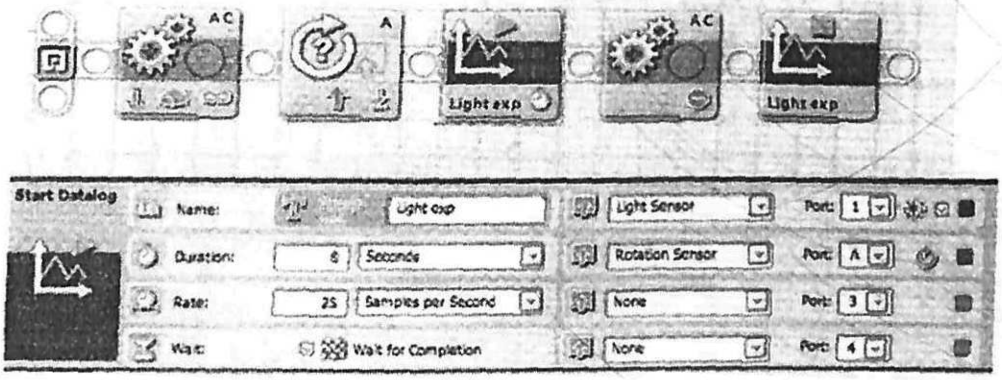


Figure 5.2.3 Robolab program.



Start Datalog

Name: Light exp

Duration: 6 Seconds

Rate: 25 Samples per Second

Wait: Wait for Completion

Light Sensor Port: 1

Rotation Sensor Port: A

None Port: 3

None Port: 4

Figure 5.2.4 Mindstorms 2.0 program

Activity Instructions:

1. After downloading the program, set up the light source and car so that the room has, as little external light as possible.

2. Start not too closely to light, so that intensity is less than 100%.

3. Run the car so it moves away slowly in a straight line, still in sight of the light.

4. Data can be uploaded using Mindstorms, Robolab Investigator or using Front Panel Indicators.

5. Graphs of rotation angle and light Intensity versus time can be displayed. If possible combine these to graph Light Intensity versus number of rotations.

Student Observations and Analysis:

Observations and Analysis

1. Did the car move uniformly?

2. How did the light intensity vary over time?

Reflection Questions:

1. What can you conclude about light intensity versus distance from the source?

2. If possible determine the relationship between light intensity and distance.

3. What factors affected the accuracy of this experiment?

4. Is the NXT light sensor the best for this experiment, if it measures levels of Infrared light?

5. Does changing size and power of the light source have any effect on the results?

6. Will these results be similar for sound waves?

5.3 Conversion of Mechanical Energy into Electrical Energy

Activity Level: 14+years

Recommended Time: 40-50 minutes

Materials: NXT motor, LEGO lamps and NXT conversion cable, pulley and a string, mass with a hanger, Vernier current and voltage probes.

Activity Overview: When falling water rotates, the rotor of the electrical generator electricity is generated. The power generated depends on the rate of change of the potential energy of the falling water. This situation could be modeled by replacing the falling water with a weight hanging from a string that goes over the pulley attached to the motor. The power generated can be calculated from measured voltage and current values. The mechanical power can be calculated as the change of the mechanical energy of the weight per unit of time.

Learning Objectives:

Students will design a setup for the experiments consisting of the NXT motor, pulley, string, and a set of weights to demonstrate the energy conversion.

Students will experimentally study the efficiency of the conversion of mechanical energy to electrical energy for different electrical loads.

Activity Instructions:

In this experiment, the NXT motor will be used as generator. An electrical generator is a device that converts mechanical energy into electrical energy. If the rotor of the generator is rotating, electrical voltage is produced and the current can flow through the load (one or more LEGO lamps in our case).

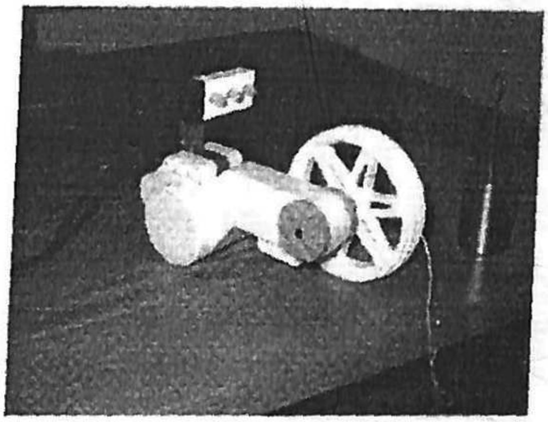


Figure 5.3.1 Experimental set-up

Fix the motor to the tabletop or hold it in your hand. Hang a weight from the string and test your system. While the hanging weight moves down, observe that the LEGO lamps emit light. The brightness of the lamp depends on the power dissipated in the lamp.
The power is the rate of producing work $P = Work/Time$

The electrical power is defined as a product of voltage (V) and current (I), $P = VxI$

1. Using Vernier current and voltage probes make a circuit shown in Figure 5.3.2.

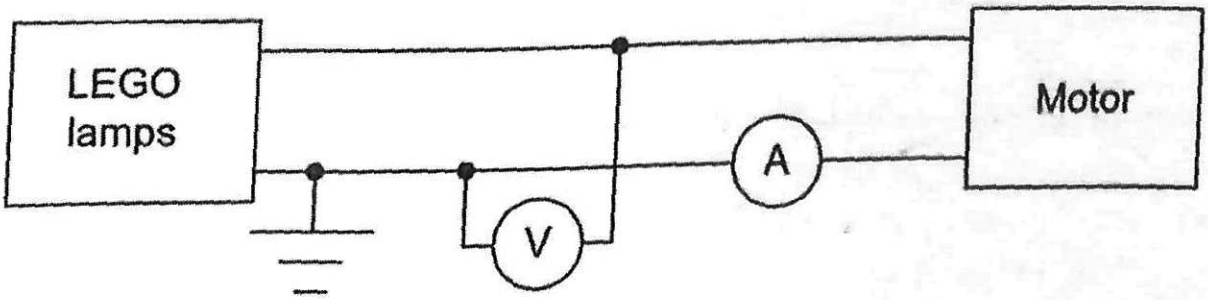


Figure 5.3.2: Electrical circuit diagram of the experiment.

By what means do you produce electrical power delivered to the LEGO lamp?

Rotating the pulley you produce the mechanical work. The faster you produce this work the larger is the mechanical power.

Let's consider the simplest case: when the force exerted on the pulley is constant and the speed of the falling weight is constant. In our set-up, the falling mass will quickly reach equilibrium and therefore fall with a constant speed (terminal speed).

In the case when work is produced due to the constant force applied to the pulley, work = force x distance (parallel), and it is called mechanical work.

For the simple case when the object is moving with constant speed through the distance (d), the work (W) produced by the force (F) is $W= FxL$.

In your experiment you will measure mechanical power produced due to the lowering of a weight and you will measure the electrical power delivered to the lamp. The more of the mechanical work converted into electrical work, the larger the efficiency of the process.

2. Connect one LEGO lamp and while holding the pulley stationary, connect a weight to the string on the pulley. Now, release the pulley and let the weight fall. If the weight doesn't move right away, slightly rotate the pulley to start the motion. What can you say about the motion of the weight? Is it moving with a constant speed or with increasing speed?

3. Repeat the experiment while collecting quantitative data by measuring current, voltage, distance traveled by the hanging mass, and the time it takes to travel this distance. Record the data in Table 5.3.1. See Figure 5.3.3 with sample data from Vernier current and voltage probes.

4. Connect two LEGO lamps and repeat the experiment. What can you say now about the speed of the moving weight?

5. Connect three LEGO lamps and repeat the experiment. What can you say now about the speed of the moving weight?

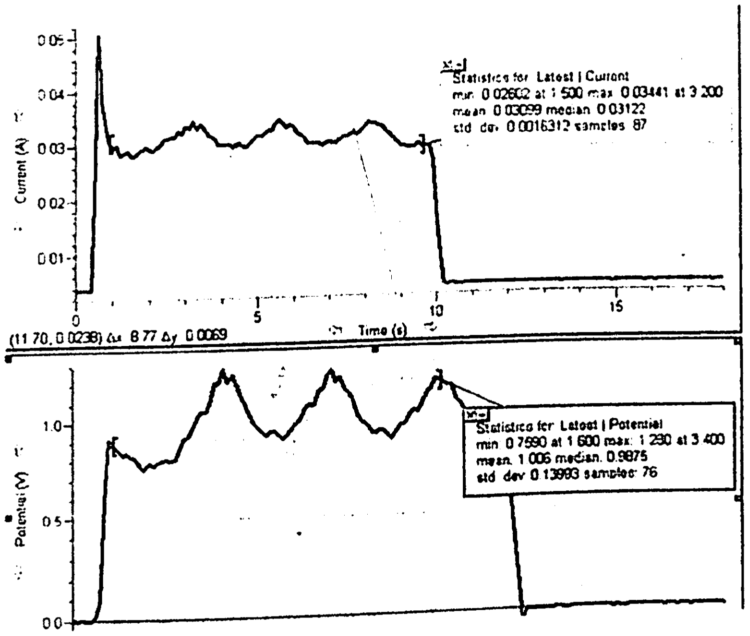


Figure 5.3.3 Current and Voltage produced by the generator.

Using this data, calculate mechanical power developed by the moving mass and electrical power produces by the generator and the efficiency of this conversion of mechanical energy to electrical energy. Record the data in Table 5.3.1.

Student Observations and Analysis:

Table 5.3.1

Weight (N)	Load (#of lamps)	Time, t(s)	Height, h(m)	Work, W(J)	Mechanical Power, P_m (Watt)	Voltage, V (Volts)	Current I (Amps)	Electrical Power, P_e (Watt)	Efficiency (%)
1.5	1								
	2								
	3								

5.4 Battery Investigation

Age Group: 14+

Essential Question: Which makes the motor spin faster - bigger or smaller batteries?

Recommended Time: 30 minutes.

Materials: LEGO motor (NXT or RCX),NXT conversion cable if NXT motors are used, assorted Batteries (e.g. AAA,AA,C,9V), multi-meter Switch (optional) RCX wire (see building instructions).

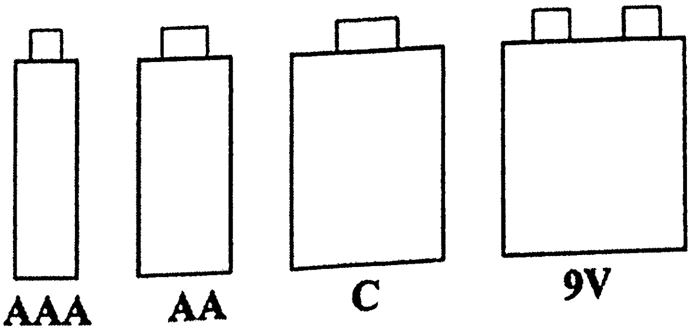
Activity Overview: In this activity students will be connecting a LEGO motor to various batteries to test their assumptions about the effect these batteries have on the speed of a motor. Motors offer students a visual and auditory response to the current supplied by each battery. This lab will challenge their assumptions about batteries and help them build a new understanding about how batteries and circuits work.

Pre-Activity Discussion Questions:

1. What is the difference between voltage and current?

2. What determines how long a battery will last?

3. Prediction: Look at the picture below. Predict the effect the batteries used in this lab will have on the speed of the LEGO NXT motor. Use the diagram below and label each battery in the drawing:



Learning Objectives:

By the end of this activity students will be able to:

1. Define voltage

2. Define current

3. Measure electrical current in a circuit

4. Identify a trend in the relationship between voltage and current

5. Define battery capacity

6. Identify battery design features that affect its capacity and the current produced in an electrical circuit.

Building Ideas:

To connect your LEGO Motor to the batteries, you will need a modified RCX cable. The following steps document how to modify the RCX cable to work in this and other lab investigations involving electricity measurements.

1. Measure your RCX cable and look at the two images below. Cut the cable such that both ends are long enough to use in your circuit. Separate and strip the cable (see Figure 5.4.1).

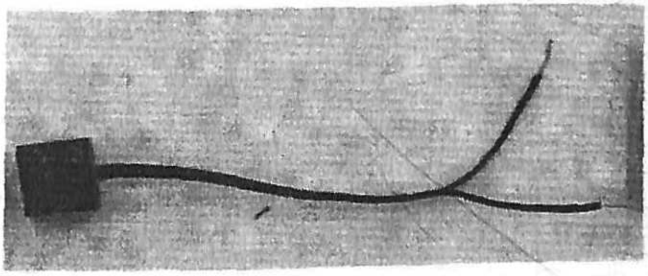


Figure 5.4.1. Modified RCX cable.

2. Repeat step #1 and make three modified cables to build the circuit shown in Figure 5.4.3. NOTE: on the next pages we show an alternative step that allows you to build the circuit while only modifying two RCX cables.

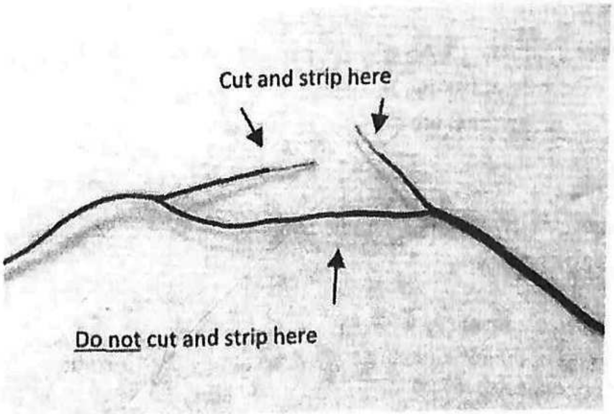


Figure 5.4.2. Another modified RCX cable. This one is well sustained for current measurements.

3. Alternative Step - It is possible to make the circuit diagram by modifying only one of the two parallel wires in the RCX cable (Figure 5.4.2. Using a sharp knife, carefully

separate the two parallel wires for a distance of approximately three cm. Cut and strip the ends of one of these wires. This will allow you to connect your multi-meter and complete the electric current measurement necessary for this lab.

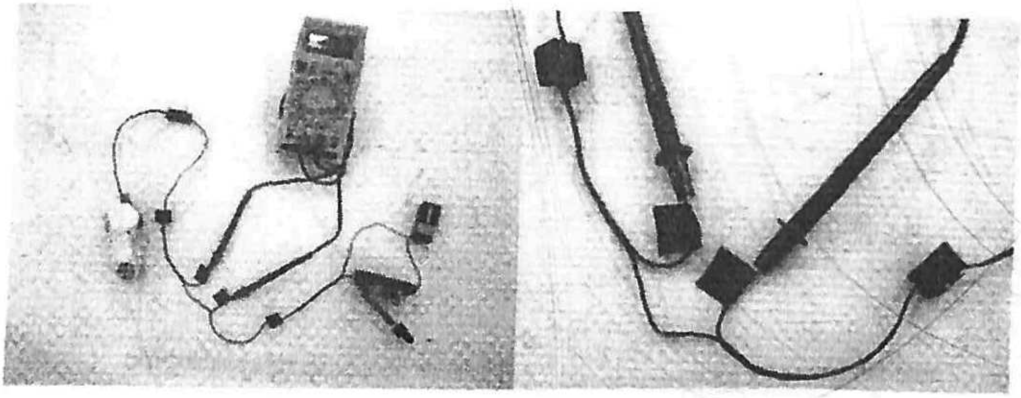


Figure 5.4.3. Experimental design used during this activity.

Activity Instructions:

1. The goal of this activity is to test your predictions about the affect each battery will have on the speed of a LEGO motor. To do this, test each battery separately.

2. Measure the voltage of each battery and record it you observation table. Do this for each battery before moving on to the next step.

3. Connect the battery, motor, multi-meter, and optional switch as shown in Figure 5.4.3.

4. Turn on the motor by closing the switch or connecting the final wire to the battery. Observe the amount of current flowing through the circuit. Write this down in your observation table.

5. Observe speed of the motor compared with the other batteries you test. A simple method for measuring the rotational speed of the motor is to attach a gear or some other LEGO piece that allows you to easily count the number of rotations in a unit of time.

Student Observations and Analysis:

Battery	Voltage Measured	Current Measured	Observation of Motor Speed (revolutions per unit of time)
AAA			
AA			
C			
9V			

Reflection Questions:

1. Based on what you observed, rank order the batteries in terms of which one made the motor go slowest and which one made it move the fastest.

2. Did the size of the battery impact the speed of the motor? Does the size of the battery have any effect at all?

3. What effect does the voltage of the battery have on the current moving in the circuit? What affect does it have on the motor's speed?

5.5 Investigating the Solar Cell

Age Group: 14+

Essential Question: How do you get the most out of your Solar Cell?

Recommended Time: 40- 50 minutes.

Materials: Motor, motor connector, LEGO solar cell, NXT/RCX Brick, light sensor, touch sensor and any materials, filters you may want to test.

Activity Overview: The aim is to compare the light readings of a light sensor to voltage readings of a Solar Cell at various light levels to determine optimum conditions for the solar cell to collect power.

Learning objectives:

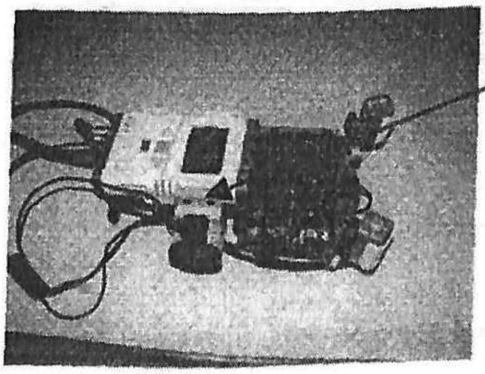
1. Model and analyze energy transformation.
2. Design and perform controlled investigations.
3. Refine investigations after evaluating variations and inconsistencies

Pre-Activity Discussion Questions:

1. It is obvious that full daylight in direct sun will generate power from a solar cell. But, what if that's not possible - how do you find the best spot in a classroom?
2. Where and how can a Solar cell continue to provide adequate power?
3. What factors affect the amount of light getting to a cell and what type of light is required?
4. What effects do different filters have on light intensity?
5. Does reflected light significantly reduce the intensity?
6. How does transmitted light through glass and/or plastic compare?
7. What about artificial light?

Building Ideas:

1. Attach a solar cell to a motor. Check that it works in some light. The motor acts as a resistance sensor. The solar cell when fully functioning uses no power (0 V) and must be connected to a load to measure the potential drop and voltage supplied.



Legacy Motor attached to Solar Cell and port 2 on NXT.

Figure 5.5.1: Experimental setup

2. Attach the touch sensor to port 1, motor to port 2, and light sensor to port 3.

Programming:

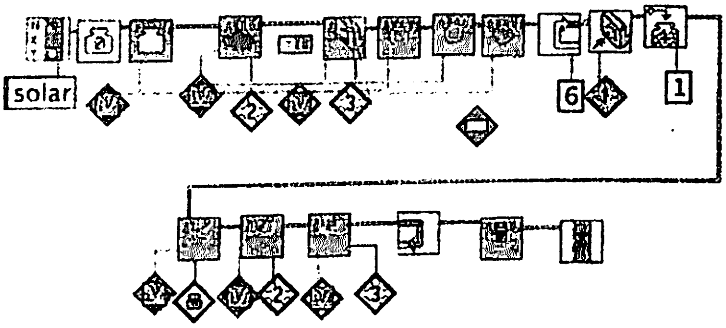


Figure 5.5.2: Sample Robolab program: Solar Cell

To make this program:

1. Choose Inventor 4 in ROBOLAB 2.9.

2. Data log the voltage across the motor as a generic voltage sensor using the generic icon.

3. Data log the light sensor on port 3.

4. Use free sampling so that the collection is based on the touch sensor on port 1 as the mode for initiating readings.

5. Also data log the number of readings using a container.

6. Take as many data logging readings as required.

7. You can view the data a number of ways:

   a. Using Detective - Data Log View

   b. Using Investigator - copy and paste this program in Program Level 4

Activity Instructions:

1. Decide your sites for data collecting and record the results in a table in the order you take them.

2. Download and run the NXT/RCX clicking the Touch sensor each time to record readings of light and voltage in each of the places.

3. Upload data for two data sets (light and voltage).

4. Repeat recordings if necessary to confirm results.

Student Observations and Analysis:

Site	Light %	Voltage

Reflection Questions:

1. Which areas show greatest light values?

2. Which areas show greatest voltage values?

3. Is voltage always in proportion with light level?

4. What other factors are involved?

5. What conclusions can you make about voltage and light levels?

Notes and Extensions:

1. The LEGO Solar Cell has a maximum 3 V and 200mA.

2. Students should find a threshold light level for the Solar Cell to generate current.

3. Frequency of light is important too, so testing various filters for optimum colors is important.

4. Some bright lights such as Fluorescents does not produce much voltage.

5. This activity is an excellent investigation as part of an alternative energy unit on solar power.

6. Students can investigate efficiency issues with the solar cell. It is difficult to compare sunlight power absorbed and electrical power produced because of measuring irradiance directly but comparisons to the maximum output power of 0.6 W could be done by measuring current and voltage across the motor.

7. It also fits in well with photoelectric theory and the atom.

8. Engineering activities involving the use of a Solar Cell:

a. A light-seeking robot that finds the best spot for its solar power.

b. A motor controlled platform for the solar cell that follows the sun.

c. A capacitor LED night-light, charged by the solar cell.

5.6 Parallel and Series Circuits

Age Group: 14+

Essential Question: When a light bulb goes out in your house, do all the other bulbs go out as well?

Recommended Time: 45 minutes.

Materials: 3 LEGO motors, 3 NXT conversion cable, 3 AA Batteries, modified LEGO connecting wire, one 9-volt battery, battery holders.

Activity Overview: In this activity, students will build parallel and series circuits out of LEGO motors and batteries. The motors represent the light bulbs in the question above. Motors offer students a visual and auditory response to the current running in each circuit arrangement. By connecting motors and batteries in parallel and series circuits, students will not only learn the effects a circuit arrangement has on a motor but also the practical application of parallel and series to the electric circuits in every-day life.

Pre-Activity Discussion Questions:

1. What is the difference between parallel and series circuit connections?

Learning Objectives:

By the end of this activity students will be able to:

- Build parallel and series circuits

- Explain the effect circuit design (i.e. parallel or series) has on the performance of both motors and batteries

Building Ideas:

To connect your LEGO Motor to the batteries, you will need a modified RCX cable.

Activity Instructions:

1. On a separate sheet of paper, draw circuit diagrams (schematics) for the following circuits:

a. 1 motor and 1 battery

b. 2 motors in series with 1 battery

c. 3 motors in series with 1 battery

d. 2 batteries in series with 1 motor

e. 3 batteries in series with 1 motor

f. 2 motors in parallel with 1 battery

g. 3 motors in parallel with 1 battery

h. 2 batteries in parallel with 1 motor

i. 3 batteries in parallel with 1 motor

2. Look at Table 1 in the student observation section of this activity. These are the circuits you must build and observe. Build each circuit in Table 1 using the appropriate battery, circuit arrangement, and LEGO motor(s). Measure and record motor speed as a way to document the effect that the circuit arrangement has on the motor's performance.

Student Observations and Analysis:

Circuit Description	Observation of Motor Speed (revolutions per unit of time)
1 motor and 1 nine-volt battery	
2 motors in **series** with 1 nine-volt battery	
3 motors in **series** with **1** nine-volt battery	
1 AA battery and 1 motor	
2 batteries in **series** with 1 motor	
3 batteries in **series** with 1 motor	
2 motors in **parallel** with 1 nine-volt battery	
3 motors in **parallel** with 1 nine-volt battery	
2 AA batteries in **parallel** with 1 motor	
3 AA batteries in **parallel** with 1 motor	

Reflection Questions:

1. Summarize your findings about connecting additional motors in series with a single battery.

2. Summarize your findings about connecting additional batteries in series with a single motor.

3. Summarize your findings about connecting additional motors in parallel with a single battery.

4. Summarize your findings about connecting additional batteries in parallel with a single motor.

5. What are the advantages and disadvantages of connecting motors in series?

6. What are the advantages and disadvantages of connecting batteries in series?

7. What are the advantages and disadvantages of connecting motors in parallel?

8. What are the advantages and disadvantages of connecting batteries in parallel?

9. How do the observations you made in this lab relate to circuits that you interact with in everyday life? Explain at least two examples.

10. Why do you think that two different types of batteries were used in this activity?

6. Challenges and Projects

6.1 NXT Distance Match Problem Solving Challenge

Age Group: 15+years

Challenge: Make a LEGO car match a motion graph constructed by your partner involving up to three steps with varying speeds (positive, stop and negative for varying times).

Recommended Time: 40 - 50 minutes.

Materials: Use an NXT LEGO car with at least one motor encoder, MINDSTORMS'/ROBOLAB Software.

Activity Overview: Work in groups of two. The Challenge is in two parts:

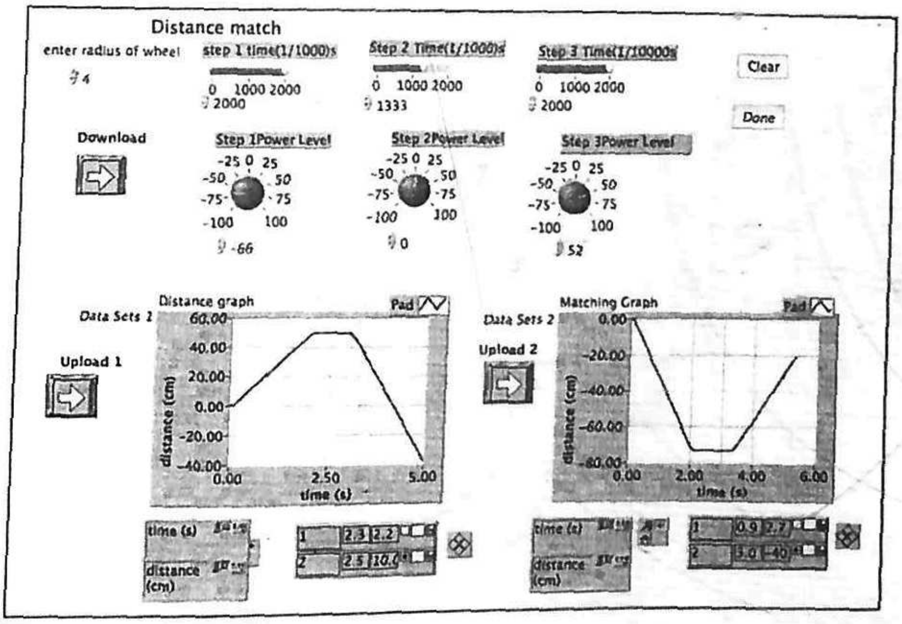
1. Generate a three-stage motion graph (Distance versus Time) with a car for your partner to analyze.
2. Analyze your partners graph and reproduce it with your car.

Learning Objectives:

1. Apply physics concepts to construct and analyze stages of motion.
2. Determine speed from a distance - time graph.
3. Applying a known mathematical relationship to a problem.

LEGO Sample Building Instructions:

You can use any NXT car (one motor is sufficient).



Distance match

enter radius of wheel 4

step 1 time(1/1000)s 2000

Step 2 Time(1/1000)s 1333

Step 3 Time(1/10000s 2000

Step 1Power Level -66

Step 2Power Level 0

Step 3Power Level 52

Figure 6.1.1 Sample Front Panel Window.

Activity Instructions:

Part 1

1. Using the Front Panel Controls, generate a Three Step Distance Graph for your partner to analyze and match.

2. This is done by entering time and power level, downloading to your car, running it and then uploading the data.

3. Reset the controls. You don't want to give your partner any help!

Part 2

1. Now analyze your partners graph by determining power levels and times required from the graph.

2. When power levels and times are determined enter the data and run your car.

3. Upload the data to the second Matching Graph.

4. Compare graphs and use the reflection questions to explain differences.

Observations and Analysis:

	Distance	Time	Speed	Power level required
Step 1				
Step 2				
Step 3				

Reflection Questions:

1. Did the times match for each stage?

2. Did the distances match for each stage?

3. What caused the differences?

Notes and Extension:

1. The students need to have determined speed from distance - time graphs.

2. It is important students can work together to challenge each other.

3. Follow up extension activities to this include:

a. Matching Velocity - Time graphs

b. Matching Acceleration Time graphs

c. Do a speed control activity such as a "Traffic Zone". For example consider a "school zone" where the model car would travel at 1 m/s then slow down to 0.5 m/s for 1 meter past a model school. The same could be done for a "construction zone or any other type of "traffic zone".

6.2 Ten Second Timer

Age Group: 16+

Essential Question: Given some LEGO pieces and a LEGO weight, can you make a simple device that accurately times 10 seconds?

Recommended Time: 90-180 minutes.

Materials: LEGO beams, plates, pegs NXT or RCX LEGO weight, light sensor.

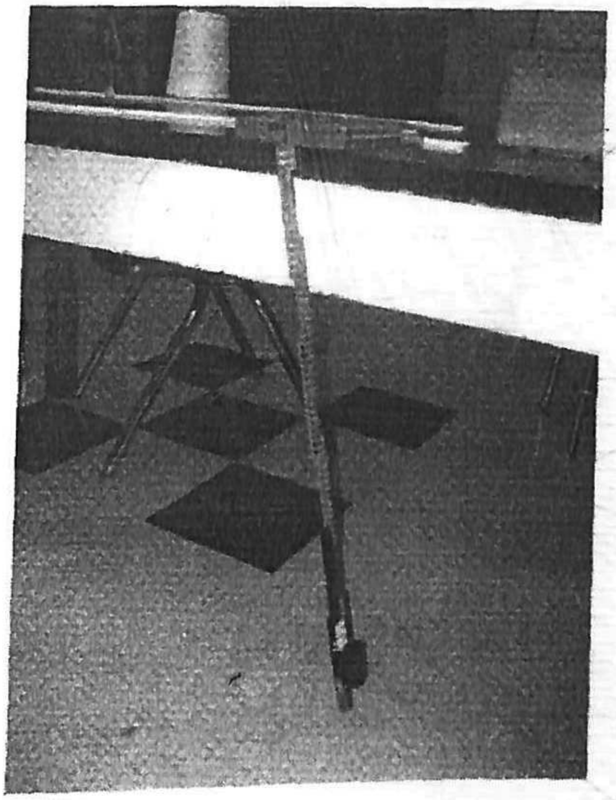


Figure 6.2.1 sample 'LEGO Pendulum'

Activity Overview: In this activity, students will determine how well the equation for a simple pendulum predicts the period of a physical pendulum constructed from LEGO Beams and LEGO weights. They will do this by:

1. Designing a LEGO Beam physical pendulum that accurately times ten seconds with a whole number of swings.

2. Building their 'ten second timer."

3. Finally, using the sensors from an RCX or NXT kit, students will create a system that tests the accuracy of a "10 second timer".

Pre-Activity Discussion Questions:

1. How are pendulums used in clocks?

2. As a pendulum's swing (amplitude) becomes smaller, what happens to its period?

3. What is the difference between a physical pendulum and a simple pendulum?

4. What is the mathematical relationship that determines the period of a simple pendulum?

5. What does "center of mass" mean and how can you determine the center of mass for a LEGO Beam physical pendulum?

6. How can you use the relationship for determining the period of a simple pendulum and a working knowledge of "center of mass" as a starting point for making a prediction regarding the period of a LEGO Beam physical pendulum?

Learning Objectives:

By the end of this activity students will be able to:

1. Use an idealized system (simple pendulum) to make predictions about a real world system (physical pendulum).

2. Identify the location of a center of mass of a system.

3. Refine predictions about a systems behavior based on careful observations.

4. Predict characteristics of a physical pendulum and engineer a 10 second timer.

5. Create a system that tests the accuracy of a 10 second timer.

6. Identify sources of human error and create a system that minimizes or eliminates human error.

Building Ideas:

In the three parts of this activity, students will build two systems. They will build physical pendulums and an RCX or NXT based system to measure the performance of a physical pendulum.

Figure 6.2.2 shows the pieces of a basic physical pendulum system made from LEGO parts. In the pictures, you will notice four key parts to the system:

1. LEGO beams

2. LEGO Weight Element

3. Top plate and support to keep the pendulum stationary

4. Axle for pendulum rotation

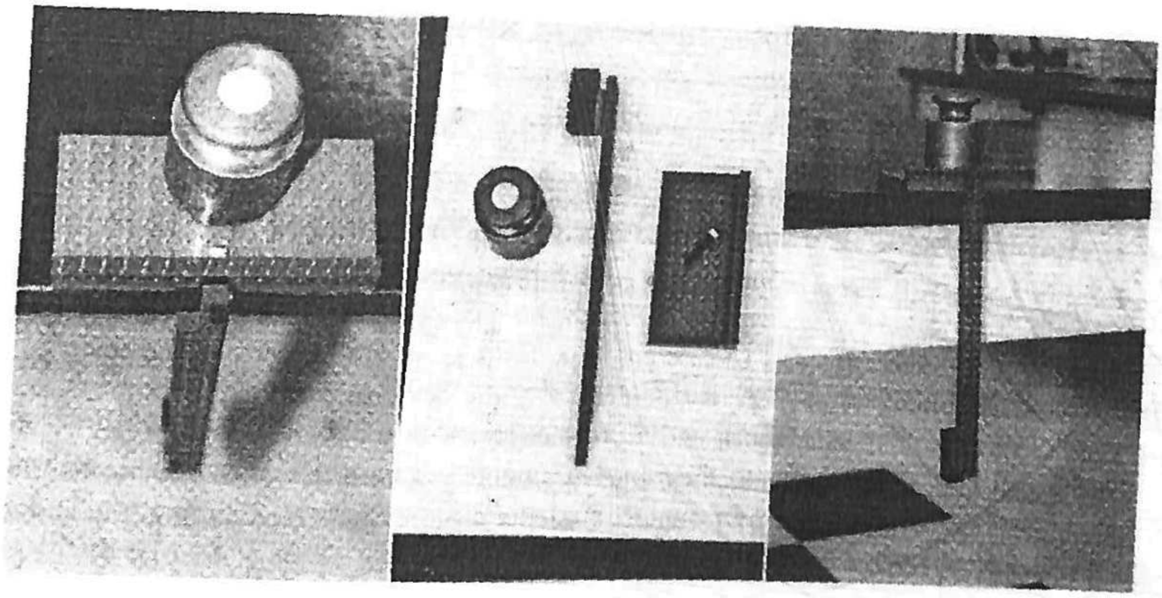


Figure 6.2.2 Physical pendulum created from LEGO parts.

An example NXT system for measuring the performance of the activities culminating challenge - the "ten second timer". Here, you see the pendulum being tested, the NXT with a light sensor, and a piece of paper behind the pendulum. The paper serves as a highly reflective surface to improve the light sensor readings. The way this testing system works is as a "break beam" type system. The NXT uses the light sensor to count the number of times the pendulum has swung.

After a pre-determined number of swings, the NXT displays the time. For instance, if students built a pendulum to time ten seconds with five swings then this system would count five swings and display the time. The time displayed gives students clear feedback on the accuracy of their pendulum.

Programming Ideas:

A system to measure the performance of a ten second timer can become quite complex. For starters, however, I encourage you and your students to explore the most straightforward method. Figure 6.2.3 shows the Mindstorms code for this method. The NXT simply becomes an egg timer, beeping at the end of ten seconds.

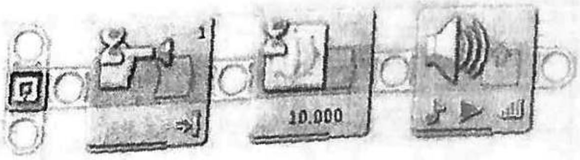


Figure 6.2.3 Mindstorms timer code.

While this code does not represent the most robust solution to the problem of measuring a ten second timer's performance, it lays out the basic components of a measurement strategy. To measure the performance of the ten second timer, the system needs to know when to begin timing (the button in this case). It then needs to provide feedback to the user on the amount of time that has transpired. In this case, it beeps after ten seconds. To use this simple system, a student starts the pendulum at exactly the same time they press the button to start the NXT code. While the NXT waits for ten seconds, the student watches her pendulum. If she predicts that it will time ten seconds after five swings then she will watch for the pendulum to complete the fifth swing. If the NXT beeps as the pendulum completes the fifth swing then she knows her timer worked.

The simplicity of this system has a downside. It requires the student to manually start the timer and observe the end state of the pendulum when the beeper goes off. More advanced solutions are judged to be robust if they can take the human out of the equation all together. The time required to design this system is likely to be more than what is allotted for this activity in your physics curriculum.

Activity Instructions:

As you complete each of the following steps, document your work and record your observations. Refer to the table in the Student Observation and Analysis section of this activity write-up as a guide.

Part 1

1. Using a collection of LEGO Beams, pegs, and LEGO weights, construct a physical pendulum.
2. Use the equation for the period of a simple pendulum to predict the period of your physical pendulum.
3. Compare your prediction with the results of your initial tests.
4. If necessary, change the equation for the period of a simple pendulum to better predict the period of a LEGO physical pendulum.
5. Create a new LEGO physical pendulum and predict its period. Test and compare with your prediction.

Part 2

6. Develop a plan for creating a physical pendulum that accurately times 10 seconds with a whole number of swings. Your plan must include a request for materials. You must use all of your materials in the design of your pendulum.

7. Obtain the materials outlined in your plan and construct your "10 second timer".

8. Once your "10 second timer" is operational you are ready for Part 3 of this activity.

Part 3

9. Create a RCX or NXT based system to test the accuracy of your "10 second timer". To ensure that your test is valid, your system must eliminate or minimize human error. See the notes and extensions section of this activity for programming tips.

Student Observations and Analysis:

After you have constructed your physical pendulum, draw what it looks like in the box to the right.			
Use the equation for the period of a simple pendulum to calculate the prediction for the period of your physical pendulum. Show your work here.			
Test the period of your physical pendulum using at least three trials.	Trial #1	Trial #2	Trial #3
Describe how you will adjust (if at all) the equation for the period of a pendulum to better predict the period of a new physical pendulum.			
Create a new physical pendulum and draw it in the box to the right.			
Test the period of your physical pendulum using at least three trials.	Trial #1	Trial #2	Trial #3
Create a plan and a list of materials needed to make a "10 second timer" from LEGO Beams, pegs, and weights. Your timer must time 10 seconds in a whole number of swings. Document your ideas and materials list in the box to the right.			
Once you have created your "10 second timer", develop a plan to test it. Document your ideas for using sensors, a RCX or NXT, and a program to test the accuracy of your "10 second timer".			
Use the space to the right to document the results of your test. Conduct three trials.	Trial #1	Trial #2	Trial #3

Reflection Questions:

1. Describe your strategy for solving this problem. What did you measure/calculate in order to design an accurate "10 second timer"?

2. Summarize the relationship between the three variables (length, mass, and pullback distance) on the period of your pendulum.

3. When conducting an investigation of the relationship between variables, why is it important to only change one variable at a time?

4. In this activity, you did a short scientific investigation and then used the knowledge gained to design a practical device - a "10 second timer". What are other examples of instances where science helps engineers to design practical devices for society?

6.3 Time for Robot Golf

Age Group: 14+

Essential Questions: Can you program a robot to score a hole in one?

Recommended Time: 45 to 90 minutes.

Materials: NXT or RCX Kit, measuring tape, stopwatch, blue painters tape to make golf holes on the floor.

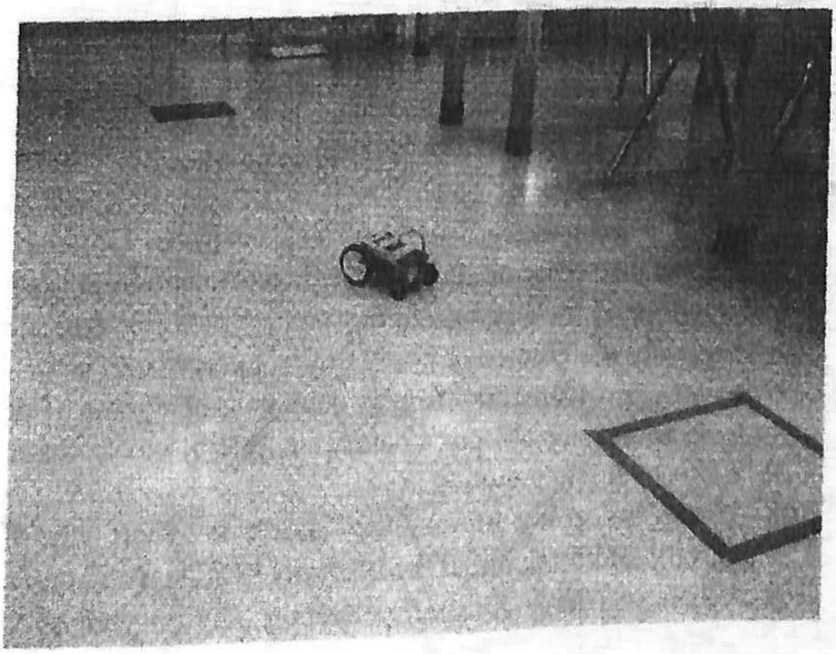


Figure 6.3.1 Photo of Classroom Setup

Activity Overview: In this activity, students will either build on previous experiences, or start from scratch to solve the problem. Students are going to play a round of robot golf. To solve the problem, they need to do the necessary measurements and calculations to predict the time the robot needs to travel to make it in the hole.

Learning Objectives:

By the end of this activity, students will be able to:

1. Interpret data to create an equation based or graph based mathematical model of an object's motion.
2. Use a mathematical model to predict the motion of an object
3. Test a prediction with an experiment
4. Refine their models based on new experimental evidence

Building Ideas:

Classroom set-up:

The number and arrangement of holes will depend on the time you have available for the activity and the design of your teaching environment. When the authors use this activity with students, they scatter the holes in amongst the lab tables of their rooms and place longer holes in the hallway. Shorter holes are on the order of 1-2 meters. Medium holes are 2-4 meters long and longer holes are 4-8 meters long.

Activity Instructions:

1. Build or use a previously built LEGO vehicle
2. Use Mindstorms or Robolab software to program your robot to travel at a certain power level for a certain time. You are now ready to start.
3. Consider the challenge posed to you by your instructor - "Figure out how much time to program your robot to play each hole in a game of golf". Before you start to play your round of golf, use a data table, graph, and/or equation to create a model of your LEGO vehicle's motion. ,
4. If you are going to vary the "power level" of your robot during this activity, be careful and think about the best way to collect and organize your data.

5. When you have finished collecting data on your robot, find the "practice green", which is 2-3 holes where you can practice before starting the game.

6. Measure the distance between the tee and the hole on the practice holes.

7. Use your mathematical model (data table, graph, and/or equation) to help you decide the time and power level to program into your robot so that it drives the distance to the hole.

8. If your robot misses the hole, measure the distance from its current spot to the hole and take an additional stroke to get it in the hole.

9. Based on your performance on the practice green, refine your model and start your game of golf.

10. Record your measurements on the provided scorekeepers card. (Table 6.3.1)

Hole	Distance to Hole	Robot Power Level	Time Calculated	Strokes
1				
2				
3				
4				
5				
6				
7				
8				
9				
			Total Strokes	

Table 6.3.1 Score Table

Student Observations and Analysis:

1. Use a data table (Table 6.3.2) and graph to create a mathematical model that allows you to accurately predict how to operate your vehicle to get the best score possible.

Time of Travel	Distance Travelled	Notes

Table 6.3.2 Robot distance and Time Data

2. From the data above draw an appropriate graph to determine any distance from the time.

Reflection Questions:

1.Describe how you played each hole. What steps did you follow?

2.Did you use the same process for each hole? Were any holes better than others? Explain.

3.Were there any errors in your process that you had little control over? Did you create a strategy for dealing with these errors?

4.To complete this game of golf, you applied your knowledge and skills in science, math, and engineering. Is this true for all athletic games? Pick an example and explain.

6.4 Design a Motorized Crane Challenge

Age group: 14+ Recommended Time: 2 hours

Challenge: Can a light LEGO based crane be made strong enough to lift more than its own weight?

Materials: LEGO pieces, RCX brick, LEGO Motor, LEGO gears and pulley, string various, brass weights 10 – 100 g

Activity Overview: This is a follow up engineering challenge to the gear ratio investigations. It is used to apply their knowledge of gear ratios and force along with construction skills. Some understanding of ties, bracing and rigid structures is also required.

Learning Objectives:

By the end of this activity students will be able to apply the following concepts:

1. Simple machines use pulleys and gears to reduce force.

2. Gantry structures consist of rigid frames, braces, struts, ties and cantilevers to balance weight.

3. Efficient energy conversions require reduction of friction and movement.

Engineering Challenge

Plan, design and build a motorized LEGO crane to lift as much weight as possible.

Building Instructions and Conditions:

1. You are limited to no more than 450 g of LEGO, 1 motor, 1 RCX/NXT Brick and 1 meter of string.

2. The crane must be a minimum of 20 cm in height (base to the arm)

3. This crane arm must extend a minimum of 20 cm (base to string) to raise weights at least 50cm using an electric LEGO motor. (See Figure 6.4.1)

4. The base can be fixed to the desk or held down.

5. The motor has to be controlled by a 9V battery source. The RCX or NXT Brick can supply this. Battery source and motor can be fitted anywhere on the structure.

6. The weight of LEGO used is limited to 450g.

7. You can use devices to aid lifting including pulleys, gears and string.

8. String can also be used to stabilize the structure. You are limited to 1 m of string altogether.

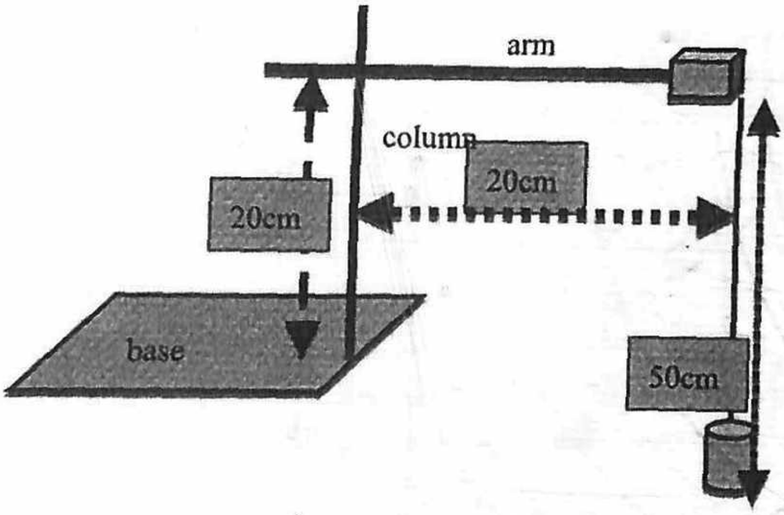


Figure 6.4.1 Diagram of specification

Activity Instructions and Assessment:

There are three parts to this assessment. You need to submit:

1. The Design and Construction of the Crane must include a folio, which shows a progression of draft diagrams. (See Table 6.4.1) Diagrams should be labelled showing Forces to be balanced.

2. Results of investigations of different scientific tests you have done to increase weight lifted.

3. Report on your final outcome, minimum 250 words. This must include:

a. *Your Best Weight Score = Weight Lifted / Weight of Crane*

b. Explanation of how you kept the Crane Stable.

c. Explanation of how you reduced energy losses to make the lifting more efficient.

d. Overall how effective was your Crane and what limitations would need to be overcome for a full-scale application?

e. Attach your folio notes.

Use sketches and descriptions to document your new ideas.	Explain why you believe your new ideas will work better.	Summarize the results of evaluation measurements (i.e. what weight it lifted, where it failed)	Describe any changes you will make to your next design
Design # 1			
Design #2			
Design #3 If you need additional space to document the results of tests on additional designs, use extra paper and attach it to your lab write-up.			
Final Design			

Table 6.4.1 Sample Folio outline

Conclusion

Using LEGO MINDSTORMS robotics activities to teach physics concepts creates an effective learning environment for conceptual knowledge development through the process of design, construction and experimental testing. In this work, I described several classroom-tested activities that target the topics of mechanics, simple harmonic motion, and electricity. I found that these experiments provide a powerful educational base by combining science investigations and engineering design, where students not only learn the concepts and the skills of physics but the practical application of their knowledge as well. Students have opportunities to develop their teamwork and communication skills and become more independent and confident learners.

Integrating robotics activities in science curriculum provides rich opportunities to engage students in real world science and help them to develop conceptual understanding of physics principles through the process of investigation, data analysis, engineering design, and construction. In addition, students become learners that are more confident and develop better problem solving and teamwork skills. In this work I describe a successful use of LEGO® MINDSTORMS® in designing robotics-based activities for teaching high school physics classes. Students design and perform novel science investigations with a toolset that helps them achieve a high reproducibility in their experimental designs.

Resources

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